Geoindicators Scoping Report for Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument

Strategic Planning Goal Ib4

June 3-5, 2002
Moab, Utah

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Contents

Scoping Summary

Introduction

From June 3-5, 2002, staff of the National Park Service, Utah Geological Survey, U.S. Geological Survey, Bureau of Land Management, Northern Arizona University, and Brigham Young University participated in a geoindicators scoping meeting in Moab, Utah for four National Park Service units in southeastern Utah. The four parks were Arches National Park (ARCH), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), and Natural Bridges National Monument (NABR).

Purpose of meeting

The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes in the four park areas. The group used collective knowledge of the four parks' geology and natural resources to identify the geologic processes active in the parks, to identify the human activities affecting those processes, and to develop recommendations for long-term monitoring of geoindicators in conjunction with park Vital Signs monitoring.

In addition, the Northern Colorado Vital Signs Network is coming on-line in fiscal year 2002 and will be receiving its first funding for Vital Signs monitoring. The scoping meeting was timed so the Network could use the information gained during the meeting in the Vital Signs selection process.

This report summarizes the group's discussions and provides recommendations for studies to support resource management decisions, inventory and monitoring projects, and research needed to fill data gaps.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at the four parks may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator background information

An international Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators guide the discussion and field observations during scoping meetings (Appendix C). The geoindicators scoping process for the National Park Service was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

Aspects of ecosystem health and stability are evaluated during the geoindicators scoping process. The geologic resources of a park—soils, caves, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility and water-holding capacities, hillside stability, and the flow regimes of surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution and structure of ecosystems, and the resistance and resilience of ecosystems to human impacts (Appendix D).

Park Selection

These parks were selected to represent the Northern Colorado Plateau Network (NPCN) of parks. The parks will be the foci of research and development for protocols associated with vital-signs monitoring at NCPN parks and monuments. Geologic resources and processes found in these four parks are generally representative of those found throughout the rest of the NCPN, and considerable geologic research has been conducted in them previously.

Summary of Results and Recommendations

During the scoping meeting, geoindicators appropriate to Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument were addressed. Of the 27 geoindicators (Appendix A), 21 were recognized as on-going processes to varying degrees in the four parks. An additional four geologic issues that are not part of the original geoindicators were also discussed (i.e., fire occurrence, atmospheric deposition, paleontological resources, and climate), as was an issue called "ecosystem response to geomorphic processes." The issues surrounding each geoindicator were identified, and participants rated the geoindicator with respect to the importance to the ecosystem, human impacts, and significance for resource managers (Geoindicators table). A compilation of the notes taken during the scoping session (Appendix G) and field trip (Appendix H) are included in the appendices. These notes may highlight additional information regarding geoindicators that may be useful to resource managers.

During the geoindicators scoping meeting, participants identified studies to support resource management decisions, inventory and monitoring projects, and research to fill data gaps at all four parks. The recommendations that follow are not listed in any order of priority, but are intended to help guide park managers when making decisions regarding natural resource management needs. The recommendations that are listed are by no means inclusive of all possible geological research and monitoring. A table that lists all the recommendations made during the meeting can be found in Appendix I.

Geoindicator table for Arches, Canyonlands, Capitol Reef national parks and Natural Bridges National Monument

Geoindicators	**Importance to park ecosystem**				***Human Impact**				****Significance to natural resource managers**			
	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE
ARID AND SEMIARID												
Soil crusts and pavements	5	5	5	5	5	5	5	5	5	5	5	5
Dune formation and reactivation	3	3	1	3	1	2	1	3	1	2	1	4
Dust storm magnitude, duration and frequency	1	1	1	1	5 1	5 2	5 1	5 3	3	3	3	3
Wind erosion (and deposition)	5	5	5	5	5 1	5 2	5 1	5 3				
SURFACE WATER												
Stream channel morphology	5	5	5	5	5	5	5	5	5	5	5	5
Stream sediment storage and load	5	5	5	5	5	5	5	5	5	5	5	5
Streamflow	5	5	5	5	5	5	5	5	5	5	5	5
Surface water quality	5	5	5	5	5	5	5	5	5	5	5	5
Wetlands extent, structure, hydrology	5	5	5	5	5	5	5	5	5	5	5	5
GROUNDWATER												
Groundwater quality	5	5	5	5	U	4	U	4	4	4	4	3
Groundwater level (and discharge)	5	5	5	5	5	5	5	5	5	5	5	5
SOILS												
Soil quality	5	5	5	5	1 5	1 5	1 5	1 5	5	5	5	5
Soil and sediment erosion (and deposition by water)	4	4	4	5	3 5	1 5	1 5	3 5	4	4	4	5
Sediment sequence and composition	1	1	1	1	4	4	4	5	3	3	3	3
HAZARDS												
Landslides, rockfalls, debris flows	3	2	2	3	1	1	1	1	1	1	1	2
Seismicity	2	1	1	1	3	3	0	0	1	1	1	1
Surface displacement (salt dissolution)	3	2	1	2	0	0	0	0	2	1	1	1
Fire occurrence	2	2	1	1	5	5	5	5	1	1	1	1
OTHER												
Atmospheric deposition (N, SO_4)	1	1	1	1	3	3	3	3	1	1	1	1
Paleontological resources	1	1	1	1	1	3	3	3	1	3	3	3
Climate	5	5	5	5	1	1	1	1	5	5	5	5
Ecosystem structure and function characteristics as integrated indicators of geophysical (i) environments, (ii) processes, and (iii) changes/disturbances.	5	5	5	5	5#	5#	5#	5#	5	5	5	5

0 - Not Applicable (N/A) 1 - LOW or <u>no substantial</u> influence on, or utility for 3 - MODERATELY influenced by, or has some utility for 5 - HIGHLY influenced by, or with important utility for U - Unknown; may require study to determine applicability	*Includes current and potential impacts. If 2 rows, top = impacts of out-of-park activities on within-park condition; bottom = impacts of within-park activities. **Synthesis of first two columns and other miscellaneous factors #process specificity

Significant geoindicators

The following is a summary of the results for the 11 geoindicators that rated the highest in all three categories, as well as the recommendations for these geoindicators that were proposed during the meeting. A summary of the scoping session discussion and the field trip are included in Appendix G and H, respectively. These notes highlight additional information regarding geoindicators that may be useful to resource managers.

Desert surface crusts (biological and physiochemical) and pavements

Biological soil crusts composed of varying proportions of cyanobacteria, lichens, and mosses are important and widespread components of terrestrial ecosystems in all four parks, and greatly benefit soil quality and ecosystem function. They increase water infiltration in some soil types, stabilize soils, fix atmospheric nitrogen for vascular plants, provide carbon to the interspaces between vegetation, secrete metals that stimulate plant growth, capture nutrient-carrying dust, and increase soil temperatures by decreasing surface albedo. They affect vegetation structure directly due to effects on soil stability, seedbed characteristics, and safe-site availability, and indirectly through effects on soil temperature and on water and nutrient availability. Decreases in the abundance of biological soil crusts relative to physicochemical crusts (which can protect soils from wind erosion but not water erosion, and do not perform other ecological functions of biological crusts) can indicate increased susceptibility of soils to erosion and decreased functioning of other ecosystem processes associated with biological crusts.

Human impacts

Off-trail use by visitors, past trampling by cattle in Arches and Canyonlands national parks, and present trampling by cattle in Capitol Reef National Park have damaged soil crusts significantly in some areas. Soil nutrient cycles, as well as most other benefits of biological soil crusts, have been compromised in these areas.

Recommendations

1. Inventory condition and distribution of biological soil crusts.
2. Investigate connection between ecosystem function and biological crusts.
3. Map crust communities in relation to environmental factors.
4. Study crust recovery rates and susceptibility to change.
5. Study crust population dynamics and conditions.

Wind erosion and deposition

In addition to water, wind is a major force that can redistribute soil and soil resources (e.g., litter, organic matter, and nutrients) within and among ecosystems. Erosion and deposition by wind is important in all four parks and can be accelerated by human activities. Accelerated losses of soil and soil resources by erosion can indicate degradation of arid-land ecosystems because ecosystem health is dependent on the retention of these resources.

Human impacts
Trampling and vegetation alteration by livestock as well as human recreational activities such as hiking, biking, and driving off of established trails and roads can destabilize soils and increase soil susceptibility to wind erosion. Some localized heavy visitation areas within parks have seen crust death by burial from windblown sands when nearby crusts have been trampled, such as in the Windows area of Arches National Park

In addition, wind erosion and sediment transport may be strongly impacted by land-use practices outside the parks. Eolian sand from disturbed surfaces may saltate onto undisturbed ground, burying and killing vegetation and/or biological soil crusts, or breaking biological soil crusts to expose more soil to erosion. Because park management practices limit or prohibit off-road travel, human impacts within the parks primarily are associated with off-trail hiking in high-use areas. Where livestock grazing or trailing is still permitted (e.g., CARE), accelerated soil erosion can be more extensive.

Recommendations
1. Monitor movement of soil materials (see Recommendations table).
2. Investigate ecosystem consequences of movement (**Contact:** Jason Neff, 303-236-1306, jneff@usgs.gov**)**
3. Investigate natural range of variability of soil movement in relation to landscape configuration and characteristics. (**Contact:** Jason Neff, 303-236-1306, jneff@usgs.gov**)**

Stream channel morphology
The morphology of stream channels impacts the vegetative structure of the riparian corridor, affects the height of the water table, and affects the energy of water flow downstream (which affects erosion rate and water quality). Stream channels are vital components of aquatic and riparian ecosystems in these arid-land parks.

Human Impacts
Potential for human impact on stream channel morphology is great. These impacts include building parking lots and structures in or near channels, building structures in floodplains (e.g., culverts and bridges), livestock grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
1. Conduct hydrologic condition assessment to identify actual and potential "problem reaches" for prioritized monitoring.
2. Once "problem reaches" are identified, monitor with repeat aerial photographs.
3. Once "problem reaches" are identified, monitor with repeated cross-sections. Some data are available for Capitol Reef, Canyonlands, and Arches national parks. (See Recommendations table).

Stream sediment erosion, storage and load
Participants added "erosion" in order to clarify and encompass the total geomorphic picture regarding stream function. The original title is "stream sediment storage and load." This geoindicator is important to the ecosystem because sediment loads and distribution affect aquatic and riparian ecosystems, and because sediment loading can result in changes to channel morphology and overbank flooding frequency.

Human impacts

The potential for human impact to stream sediment erosion, storage, and load is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations

1. Conduct research concerning ungaged stream sediment storage and load. There are no data available except on the main stem of the Colorado River at Cisco, Utah, and the Green River at Green River, Utah.
2. Measure sediment load on streams of high interest for comparative assessment. Data will provide information for making management decision.

Streamflow

Streamflow is critical to the maintenance of aquatic and riparian ecosystems. Streamflow impacts the structure of the riparian corridor, affects the height of the water table, and affects water quality and erosion rates.

Human impacts

The potential for human impact on streamflow is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations

1. Identify important hydrologic systems that would benefit from knowledge of streamflow. Existing gauging stations are located on the Green River (Green River, Utah), San Rafael River (near Green River, Utah.), Fremont River (at Cainville, Utah, and above Park at Pine Creek.), and on the Muddy River. Many other gauging stations exist (see USGS Web site). Additional data exists for streams in Capitol Reef National Park and for Courthouse Wash in Arches National Park. Other relevant data exists with the local U.S. Geological Survey, Water Resources Division.
2. Research effects of land use and climatic variation on streamflow.
3. Investigate paleoflood hydrology.

Surface water quality

For detailed understanding of the issues and what has been done with regards to water quality data for the four NPS units, see the June, 2002, trip report prepared by Don Weeks in Appendix J. There are a number of park-specific water resource reports cited in the report that are particularly pertinent.

Human impacts

The potential for negative affects on groundwater quality by human activity is significant. The following are specific issues that could impact groundwater quality:

- Herbicide use to decrease tamarisk populations.
- Trespass cattle at springs.

- Abandoned oil and gas wells within and close to NPS boundaries may result in saline waters infiltrating into groundwater supplies.
- Abandoned uranium mines and mills.
- Impacts from recreational uses (these have not been quantified).

Human impacts in Canyonlands National Park
- Old landfill in Needles District (approx. 1 mile from Visitor Center, and 3,000 ft from a domestic well) had unregulated dumping from 1966-1987.
- Texas Gulf Potash Mine located downriver from Moab on the Colorado River.

Human impacts in Arches National Park
- Contamination from the Atlas tailings pile.
- Water rights associated with springs and wells near the park boundary, particularly those associated with Courthouse Wash, Lost Spring Canyon, and Sevenmile Canyon.

Human impacts in Natural Bridges National Park
- Abandoned copper and uranium mines.

Human impacts in Capitol Reef National Park
- Natural radioactivity may occur in portions of the Fremont River where it flows through uranium-ore bearing strata of the Chinle Formation.
- Pesticide use by park managers to maintain the historic orchards.

Recommendation
1. Obtain information about existing baseline water quality data for all four parks (**Contact**: Don Weeks, 303-987-6640, don_weeks@nps.gov). Also see Don Weeks June, 2002, trip report in Appendix J.

Wetlands extent, structure, and hydrology
Wetlands are important ecosystems because they stabilize streambanks, act as filters to improve water quality, attenuate floodwaters, enhance biodiversity (important habitat for amphibians, reptiles, birds, and Threatened and Endangered Species), are highly productive in terms of biomass and nutrient productivity, and are valuable water sources for wildlife and recreationists.

Human impacts
The potential for human impacts on wetlands is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion. In addition, agricultural activities and past extirpation of beaver have affected wetlands.

Recommendations
1. Inventory location, character, and conditions of wetlands in all four parks.
2. Inventory distribution of exotic species in wetlands.
3. Monitor groundwater levels and surface elevations.
4. Investigate age-structure and populations of woody riparian plants in relation to land use history.
5. Investigate links between amphibian health attributes and wetland health.

Groundwater quality
The quality of groundwater in the parks has a high impact on hanging gardens, which are located in all four parks. Hanging gardens are unique features that contain rare plant species, and provide important wildlife habitat. Groundwater quality is also an issue for safety and health regarding water quality for human use. To further understand what the issues are and what has been done with regards to water quality data for the four NPS units, see Appendix J.

Human impacts
The potential for negative affects on groundwater by human activity is significant. All four parks identified specific issues that could impact groundwater quality.

Human impacts in Arches National Park
- Grazing near Courthouse Wash and Sevenmile Canyon springs may have affected groundwater quality.
- The effects of mining and oil and gas drilling are unknown.

Human impacts in Canyonlands National Park
- Old landfill in the Needles District had unregulated dumping from 1966-1987.
- Oil well sites had improper dewatering.
- The effects of mining and oil and gas drilling are unknown.

Human impacts in Capitol Reef National Park
- The effects of mining and oil and gas drilling are unknown.
- There is standing water in mines within the park.
- There is a National Park Service septic field near the Fremont River.

Human impacts in Natural Bridges National Monument
- The impacts of copper and uranium mining and oil and gas drilling are unknown.

Recommendations
1. Locate and inventory all seeps, springs, and hanging gardens.
2. Prioritize seeps, springs, and hanging gardens for assessment of water quality.
3. Acquire plugging records of oil and gas wells potentially connected to park groundwater systems **(Contact:** Bob Higgins, 303-969-2018, bob_higgins@nps.gov **)**.
4. Use geochemical indicators to investigate groundwater flow areas, flow directions and recharge area, and groundwater age.
5. Identify and study potential sources for groundwater quality impacts at all four parks, including those listed above (**Contact**: Don Weeks, 303-987-6640, don_weeks@nps.gov). (See Appendix J.)

Groundwater level and discharge
Outside the river corridors in Canyonlands and Capitol Reef national parks, groundwater supplies much of the water available for wildlife, and supplies 100% of the park’s water supply for human use.

Human impacts
Groundwater is a limited resource, and the potential for human impact is great. Current human impacts are poorly understood.

Recommendations
1. Inventory and research are needed concerning groundwater quality, level, and discharge.
2. Install transducers and dataloggers in wells.
3. Develop methods for measuring water discharge from seeps and hanging gardens **(Contact:** Bob Webb, 520-670-6671, rhwebb@usgs.gov**)**.
4. Investigate additional methods to characterize groundwater recharge areas and flow directions **(Contacts:** Charlie Schelz, 435-719-2135, charlie_schelz@nps.gov and Rod Parnell, 928-523-3329, roderic.parnell@nau.edu).

Soil quality
Soil quality affects moisture retention, nutrient cycling, soil-food webs, and aggregate structure. Soil also provides biogeochemical and hydrologic support for terrestrial productivity, especially vegetation growth. Soil quality degradation results in loss of certain ecosystem functions, such as nutrient cycling.

Human impacts
Due to past and present grazing in the parks, nutrient cycles have not recovered.

Recommendations
1. Assess existing soil-crust conditions in relation to potential (as an indicator of soil quality) and in relation to soil maps.
2. Repeatedly measure soil quality in disturbed sites to gain understanding of recovery rates in relation to environmental factors, such as soil texture, topographic position, and climate.
3. Quantify natural range of variability in quality in relation to environmental factors.
4. Develop predictive model for potential biological soil crust distribution/structure/function in relation to environmental factors, such as soil texture, soil chemistry, topographic position, and climate.
5. Investigate susceptibility to change (e.g., climate and UV).
6. Study resistance and resilience of soil to human disturbances.

Soil and sediment erosion and deposition by water
During the discussion of this geoindicator, participants chose to focus on water transport and deposition, therefore the words, “and deposition by water” were added to this geoindicator. Transport and/or loss of soil may result in degradation of soil quality (see Soil quality geoindicator).

Human impacts
In general, past grazing practices has caused soil erosion in all four parks. There is still occasional trespass of cattle in Arches and Canyonlands national parks and Natural Brides National Monument.

Human impacts in Capitol Reef National Park
- Grazing is still permitted.
- Topographic gradients are high; therefore, erosion along roads (both currently-used roads and those used for past practices, such as mining) and cow trails is potentially great.

Recommendations

1. Investigate/develop methods for monitoring erosion and deposition quantitatively and affordably, and determine the best locations to monitor **(Contact:** Bob Webb, 520-670-6671, rhwebb@usgs.gov).
2. Assess conditions of soil erosion (e.g., qualitative hydrologic function).

Ecosystem response to geomorphic processes

Because many types of ecosystems are highly dependent on the geomorphic process and substrate, ecosystem response to geomorphic processes is highly important to park ecosystems. Disturbance to ecosystems is inevitable, whether the disturbance is human or natural caused. Management actions that attempt to mitigate disturbances, and particularly restoration of disturbed areas, may be influenced by the types of geomorphic processes involved and/or the nature of geomorphic substrates. Knowledge of predicted ecosystem responses to disturbances may affect the decision of whether to actively rehabilitate a disturbed site or whether to allow it to recover naturally. If active rehabilitation or restoration is chosen, this knowledge should determine what types of species are suitable for the underlying geomorphic conditions. Land-use practices, as well as climatic fluctuations may have an impact on ecosystem response. The perceived significance by managers depends upon need in the wake of an important disturbance that may instigate a management response.
(**Contacts**: Bob Webb, 520-670-6671, rhwebb@usgs.gov; and Rod Parnell, 928-523-3329, roderic.parnell@nau.edu)

Recommendations

1. Acquire high quality surficial geology, soil, and vegetation maps for all four parks. Current availability of soil and geologic mapping varies among the parks.
2. Determine what to monitor, where, and with what attributes/indicators.
3. Research spatial and temporal relations among ecosystem structure and function, geologic substrates, and geomorphic processes.
4. Assess change-detection methods.

List of Participants

National Park Service

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Bob Higgins, Geologic Resources Division, Lakewood, Colorado
Alison Koch, Fossil Butte National Monument, Kemmerer, Wyoming
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Appendices

Appendix A: Descriptions of 27 Geoindicators

Geoindicators have been developed as tools to assist in integrated assessments of natural environments and ecosystems, as well as for state-of-the-environment reporting. As descriptors of common earth processes that operate in a variety of settings, geoindicators represent collectively a new kind of landscape metric, one that concentrates on the non-living components of the lithosphere, pedosphere, and hydrosphere, and their interactions with the atmosphere and biosphere (including humans).

THE GEOINDICATOR CHECKLIST: The geoindicators are available in the form of a checklist that identifies 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health.

The 27 geoindicators are:

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure (landslides)
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

The descriptions of geoindicators that follow were adapted from the geoindicators checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Each geoindicator includes a brief description, reasons for its significance to an ecosystem, and some examples of human influences from national park settings. The National Park Service uses these descriptions to facilitate discussion during scoping sessions in national parks. The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. For each scoping session, appropriate indicators are selected from the list of 27, as appropriate to the terrain and environmental issues under consideration.

Coral chemistry and growth patterns

Brief Description: Corals can be used to monitor environmental changes in the oceans and nearby coastal zone. The health, diversity, and extent of corals, and the geochemical makeup of their skeletons, record a variety of changes in the ocean surface water. These include temperature, salinity, fertility, insolation, precipitation, winds, sea levels, storm incidence, river runoff, and human inputs. Corals in coastal waters are susceptible to rapid changes in salinity and suspended matter concentrations and may be valuable indicators of the marine dispersion of agricultural, urban, mining, and industrial pollutants through river systems, as well as the history of contamination from coastal settlements.

Significance: The combination of abundant geochemical tracers, sub-annual time resolution, near-perfect dating capacity, and applicability to both current and past climatic changes establishes corals as one of the richest natural environmental recorders and archives.

Human influence: Corals respond to both natural changes in the marine environment and to anthropogenic pollution.

Desert surface crusts and fissures

Brief Description: The appearance or disappearance of thin (mm to cm) surface crusts in playas and depressions in arid and semi-arid regions may indicate changes in aridity. The formation of persistent deep, polygonal cracks in the mud and silt floors of closed basins and depressions may indicate the onset of aridification or severe drought. Surfaces may contain other desiccation features such as sedimentary dikes, evaporite deposits (especially gypsum and halite), adhesion ripples and large salt polygons.

Physical soil crusts (thin layer with reduced porosity and increases density at the surface of the soil) and biological soil crusts (a living community of lichen, cyanobacteria, algae, and moss growing on the soil surface and binding it together) are also significant indicators of the state of an ecosystem. Recovery of biological crusts may take decades to hundreds of years. The amount and extent of degration to soil crusts are excellent indicators of physical disturbance to an area.

Significance: Desert surface crusts are important because they protect the underlying fine material from wind erosion. Physical and biological crusts; in Canyonlands and Arches national parks, for instance; generally help to control wind erosion. Biological crusts fix atmospheric nitrogen for vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo. Depending on soil characteristics, biological crusts may increase or reduce the rate of water infiltration. By increasing surface roughness, they reduce runoff, thus increasing infiltration and the amount of water stored for plant use.

Human Influences: The formation of surface crusts is related primarily to natural causes, but hydrological regimes that affect crust formation and persistence may be altered by human activities, such as river diversion and groundwater extraction. Both physical and biological crusts can be affected by physical disturbances caused by wheeled or tracked vehicles, livestock hooves, and hiking and cycling. The impact is determined by the severity, frequency, and timing of the disturbance and by the size of the disturbed area.

In Arches National Park, grazing practices have impacted physical and biological crusts. Seventy-five percent of the park was grazed until 1974, and cow trespass still occurs. Soil and nutrient cycles have not recovered from this past practice (2002). Trampling by visitors at North and South Window Arch, to “get the perfect picture” or to short-cut to the parking lot, has damaged soil crusts in the area. On the boundary of Arches and Canyonlands national parks, the use of seismic “thumper” trucks during oil and gas exploration created 160 miles of roads and 110 miles of ATV tracks—all of which damaged soil crusts in the area.

Dune formation and reactivation

Brief Description: Dunes and sand sheets develop under a range of climatic and environmental controls, including wind speed and direction, and moisture and sediment availability. In the case of coastal dunes, sea-level change and beach and nearshore conditions are important factors. Organized dune systems and sheets in continental environments form from sediment transported or remobilized by wind action. New generations of dunes may form from sediment remobilized by climatic change and/or human disturbances.

Sand movement is inhibited by moisture and vegetation cover, so that dunes can also be used as an indicator of near-surface moisture conditions. Changes in dune morphology or position may indicate variations in aridity (drought cycles), wind velocity and direction [see wind erosion], or disturbance by humans.

Significance: Moving dunes may engulf houses, fields, settlements, and transportation corridors. Active dunes in sub-humid to semi-arid regions decrease arable land for grazing and agriculture. They also provide a good index of changes in aridity. Coastal dunes are important determinants of coastal stability, supplying, storing, and receiving sand blown from adjacent beaches. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients.

Human Influence: Widespread changes can be induced by human disturbance, such as alteration of beach processes and sediment budgets, destruction of vegetation cover by trampling or vehicle use, overgrazing, and the introduction of exotic species.

Sleeping Bear Dunes National Seashore has a number of prominent dunes (300-400 ft high): Sleeping Bear Dune, Empire Dunes, Pyramid Dunes, Michigan Overlook, and the Dune Climb. Most of these dunes are perched dunes and consist of a relatively thin blanket of sand that has been blown to the top of thick glacial deposits. Foot traffic and social trails have highly modified the Dune Climb and Michigan Overlook, very popular visitor sites. The Dune Climb, once a perched dune, has evolved and migrated off the plateau onto the adjacent lowland.

In Cape Cod National Seashore, migration of the dunes has caused alarm since the 19th century. Dunes have migrated into Pilgrim Lake, over homes in Provincetown, and onto roads. In the 1980s, mitigation efforts were seen as a top priority, and funding was spent on efforts such as pouring asphalt onto the dunes and revegetating the dunes.

Dust storm magnitude, duration, and frequency

Brief Description: The frequency, duration, and magnitude (intensity) of dust storms are gauges of the transport of dust and other fine sediments in arid and semi-arid regions [see wind erosion]. Desert winds carry more fine sediment than any other geological agent. An increased flux of dust has been correlated with periods of drier and/or windier climates in arid regions, historically and from proxy records in ocean and ice cores.

Significance: Local, regional, and global weather patterns can be strongly influenced by accumulations of dust in the atmosphere. Dust storms remove large quantities of surface sediments and topsoil with nutrients and seeds. Wind-borne dust, especially where the grain size is less than 10 µm, and salts are known hazards to human health. Dust storms are also an important source of nutrients for soils in desert margin areas.

Human Influence: Dust storms are natural events, but the amount of sediment available for transport may be related to surface disturbances such as overgrazing, ploughing, or removal of vegetation. Identified as single events on the scale of days in Arches and Canyonlands national parks, dust storms cause hazardous travel conditions. In addition, dust storms transport contaminated sediment from the Atlas Mine tailings pile (outside park boundary) into the employee housing area in Arches National Park.

Frozen ground activity

Brief Description: In permafrost and other cryogenic (periglacial) areas and in temperate regions where there is extensive seasonal freezing and thawing of soils, a wide range of processes lead to a variety of surface expressions, many of which have profound effects on human structures and settlements, as well as on ecosystems.

These sensitive periglacial features are found around glaciers, in high mountains (even at low-latitudes) and throughout Polar Regions. The development (aggradation) or degradation of permafrost is a sensitive and early indicator of climate change [see subsurface temperature regime].

Important geological parameters related to permafrost regions include:

1. **Thickness of the active layer**, the zone of annual freezing and thawing above permafrost, determines not only the overall strength of the ground but also many of the physical and biological processes that take place in periglacial terrains. Soil moisture and temperature, lithology, and landscape morphology exercise important controls on active layer thickness. Soil moisture and temperature depend largely on climatic factors, so that if the mean annual air temperature rises several degrees Celsius, the thickness of the active layer may change over time periods of years to decades.
2. **Frost heaving** is a basic physical process associated both with near surface winter freezing and with deeper permafrost aggradation. Frost heaving can displace buildings, roads, pipelines, drainage systems, and other structures. Many frozen soils have a much greater water content than their dry equivalents and undergo a local 10-20% expansion in soil volume during freezing. The frost heave process and the consequences of thawing are of great importance in the development of many of the unique features of cold terrains, including perennial hummocks and seasonal mounds, patterned ground, palsas, and pingos.

3. **Frost cracks** are steep fractures formed by thermal contraction in rock or frozen ground with substantial ice content. They commonly intersect to create polygonal patterns, which may lead to the formation of wedges of ice and surficial material. The frequency of cracking is linked to the intensity of winter cold. Where climate is warming, ice-wedge casts replace ice wedges over periods of decades.
4. **Icings** are sheetlike masses of layered ice formed on the ground surface, or on river or lake ice, by freezing successive flows of water that may seep from the ground, flow from a spring or emerge from below river or lake ice through fractures. The intensity of icings in the southern portions of the permafrost zone may change annually, increasing with colder winters and lower snow cover combined with autumnal precipitation. Further north, icings increase in size but decrease in number when the climate cools, and vice-versa when it warms.
5. **Thermoerosion** refers to erosion by water combined with its thermal effect on frozen ground. Small channels can develop into gullies up to several kilometers in length, growing at rates of 10-20 m/yr, and in sandy deposits, as fast as 1 m/hr. The main climatic factors controlling the intensity of thermoerosion are snowmelt regime and summer precipitation.
6. **Thermokarst** refers to a range of features formed in areas of low relief when permafrost with excess ice thaws. These are unevenly distributed and include hummocks and mounds, water-filled depressions, "drunken" forests, mud flows on sloping ground, new fens, and other forms of thaw settlement that account for many of the geotechnical and engineering problems encountered in periglacial landscapes. Even where repeated ground freezing takes place, thermokarst features, once formed, are likely to persist.
7. Permafrost terrains are characterized by a wide range of slow downslope movements involving **creep**, such as rock glaciers and gelifluction, and by more rapid landslides and snow avalanches [see slope failure].

Significance: Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands, mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further (global) climate change by the release of carbon and other greenhouse gases during thawing. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

Human Influence: The freezing and thawing of soils and surficial materials and the consequent ground changes are natural processes controlled by climatic conditions, and can be modified by human actions in and around settlements and engineering works.

Frozen ground activity (frost heave and gelifluction) is a major geologic process active in Rocky Mountain National Park. Patterned ground (e.g., stone polygons and stone stripe features) occurs in high alpine areas. These features are thought to form from frost heave and frost cracking and are extremely sensitive to human disturbance. Visitors have access to patterned ground along the "Tundra World Nature Trail." There is limited parking in this area, which may cut down on the number of visitors who access the patterned ground. Furthermore, visitors are asked to fan out when walking across these surfaces to minimize disturbance of these features.

<u>Glacier fluctuations</u>

Brief Description: Changes in glacier movement, length, and volume can exert profound effects on the surrounding environment, for example through sudden melting which can generate catastrophic floods, or surges that trigger rapid advances. Twice in the last hundred years the Muldrow Glacier in Denali National Park and Preserve has "surged" flowing over lower stagnant ice and making a jumble of broken ice-blocks. Movement along the fault at or the bend may trigger a surge.

Standard parameters include mass balance and the glacier length, which determines the position of the terminus. The location of the terminus and lateral margins of ice exerts a powerful influence on nearby physical and biological processes. Through a combination of specific balance, cumulative specific balance, accumulation area ratio and equilibrium-line altitude, mass balance reflects the annual difference between net gains (accumulation) and losses (ablation). It may also be important to track changes in the discharge of water from the glacier as indicators of glacier hydrology. Abrupt changes may warn of impending acceleration in melting, cavitation, or destructive flooding.

Significance: Glaciers are highly sensitive, natural, large-scale, representative indicators of the energy balance at Earth's surface in polar regions and high altitudes. Their capacity to store water for extended periods exerts significant control on the surface water cycle. The advance and retreat of mountain glaciers creates hazards to nearby human structures and communities through avalanches, slope failure, catastrophic outburst floods from ice and moraine-dammed lakes. Notwithstanding local glacier advances, the length of mountain glaciers, and their ice volume have decreased throughout the world during the past century or two, providing strong evidence for (global) climate warming, though there may also be local correlations with decreasing precipitation.

Human Influence: Glaciers grow or diminish in response to natural climatic fluctuations. They record annual and long-term changes and are practically undisturbed by direct human actions.

Groundwater quality

Brief Description: The chemistry (quality) of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes. The relatively slow movement of water through the ground means that residence times in groundwaters are generally orders of magnitude longer than in surface waters.

As in the case of surface water quality, it is difficult to simplify to a few parameters. However, in the context of geoindicators, a selection has been made of a few important first-order and second-order parameters that can be used in most circumstances to assess significant processes or trends at a time-scale of 50-100 years. The following first order indicators (in **bold**) of change are proposed, in association with a number of processes and problems, and supported by a number of second order parameters:

1. **Salinity**: **Cl**, SEC (specific electrical conductance), SO_4, Br, TDS (total dissolved solids), Mg/Ca, $\delta^{18}O$, $\delta^{2}H$, F
2. **Acidity & Redox Status**: **pH, HCO_3, Eh**, DO, Fe, As
3. **Radioactivity**: **^{3}H**, ^{36}Cl, ^{222}Rn

4. **Agricultural Pollution**: $\mathbf{NO_3}$, SO_4, DOC (dissolved organic carbon), K/Na, P, pesticides and herbicides
5. **Mining Pollution**: $\mathbf{SO_4}$**, pH**, Fe, As, other metals, F, Sr
6. **Urban Pollution**: **Cl,** $\mathbf{HCO_3}$**, DOC**, B, hydrocarbons, organic solvents

During development and use of an aquifer, changes may occur in the natural baseline chemistry that may be beneficial or detrimental to health (e.g., increase in F, As): these should be included in monitoring programs. The quality of shallow groundwater may also be affected by landslides, fires, and other surface processes that increase or decrease infiltration or that expose or blanket rock and soil surfaces, which interact with downward-moving surface water.

Significance: Groundwater is important for human consumption on a global scale, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution.

Human Influence: Changes in natural baseline conditions may occur over the timescales of interest, and may be measured at an individual borehole or spring. Superimposed on these, however, are the greater impacts of the human activities.

Practices in parks may influence groundwater quality. Approximately one mile south of the Canyonlands Visitor Center (Needles District) is an abandoned landfill that operated from 1966 to 1987. Hazardous substances including paint thinners, pesticides, human wastes, and oils were disposed at this landfill during operation. The soils consist of alluvial and eolian deposits (loose sandy material) of high permeability 10 to 20 feet deep; thus the potential for groundwater contamination exists in the area. The closest domestic well is 3,000 feet north of the landfill.

Groundwater chemistry in the unsaturated zone

Brief Description: Water moves downwards through porous soils and sediments and, under favorable conditions, may preserve a record of weathering processes, climatic variations (in the Cl or isotopic signature), or human activities such as agriculture (NO_3) and acidification (H^+). This indicator may be considered as the output from the soil zone and may reflect the properties or change in properties of soils. Rates of downward movement are typically 0.1 to 1.0 m/yr, and a record of individual events (resolution 1-20+ years) may be preserved over a scale of decades or centuries [see groundwater quality; soil quality]. In contrast, records collected over periods of years are needed to establish trends from the monitoring of rivers and streams or groundwater discharge [see groundwater quality; surface water quality]. The unsaturated zone is also an important buffering zone for attenuation of acidity, metal content, and some other harmful substances.

Significance: Changes in recharge rates have a direct relationship to water resource availability. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality.

Human Influence: Depending on land use, the unsaturated zone beneath a site may record the effects of human activities such as agriculture and industrial activity, or regional problems such as acidic deposition.

Groundwater level

Brief Description: Groundwater is replenished from precipitation and from surface water, but the rate of abstraction (withdrawal by humans) may exceed the rate of natural recharge, leading to reduction of the resource. Some aquifers, especially in arid and semi-arid regions, contain paleowaters (fossil groundwater) stored from earlier periods of wetter climate: the reduction of these reserves is comparable to "mining." In alluvial plains, reduction in streamflow reduces the rate of natural recharge to aquifers. Measurement on a regular basis of water levels in wells and boreholes or of spring discharge provides the simplest indicator of changes in groundwater resources. However, springs may be perennial, intermittent, or periodic, and their discharge may depend on changes in climate, tides, and local underground conditions such as changes in rock stresses.

Significance: The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge: groundwater mining is a terminal condition.

Human Influence: There are natural changes in groundwater levels because of climate change (drought, pluvial episodes), but the main changes are due to human abstraction. In many places artificial recharge of aquifers is accomplished deliberately by pumping or as an indirect result of irrigation.

The majority of available fresh water in Cape Cod National Seashore is groundwater. On the lower Cape, all groundwater has local precipitation as its source. The groundwater resource directly supports most of the lower Cape's surface water—ponds, streams, and fresh water wetlands. The human populations of the lower Cape are also entirely dependent on the groundwater for private and municipal water supply.

There are three primary groundwater withdrawal concerns facing the National Seashore as development continues and the demand for new private and public water wells increases. First, excessive groundwater withdrawals can lower the local water table, potentially depleting pond, wetland, and vernal pool water levels. Second, large-scale, sustained pumping can decrease aquifer discharge, impacting streams and estuaries. Finally, under extreme cases, the groundwater volume may be depleted to a point where salt water intrudes and contaminates the fresh groundwater.

Karst activity

Brief Description: Karst is a type of landscape found on carbonate rocks (limestone, dolomite, marble) or evaporites (gypsum, anhydrite, rock salt) and is typified by a wide range of closed surface depressions, well-developed underground drainage system, and a paucity of surface streams. The highly varied interactions among chemical, physical, and biological processes have a broad range of geological effects including dissolution, precipitation, sedimentation, and ground subsidence. Diagnostic features such as sinkholes (dolines), sinking streams, caves, and large springs are the result of the solutional action of circulating groundwater, which may exit to entrenched effluent streams. Most of this underground water moves by laminar flow within narrow fissures, which may become enlarged above, at, or below the water table to form subsurface caves, in which the flow may become turbulent. Caves contain a variety of dissolution features, sediments, and speleothems (deposits with various forms and mineralogy, chiefly calcite), all of which may preserve a record of the geological and climatic history of the area. Karst deposits and landforms may persist for extraordinarily long times in relict caves and paleokarst. Karst can be either a sink or a source of CO_2, for the karst process is part of the global carbon cycle in which carbon is exchanged between the atmosphere, surface and underground water and carbonate minerals. Dissolution of carbonates, which is enhanced by the presence of acids in water, ties up carbon derived from the rock and from dissolved CO_2 as aqueous HCO_3-. Deposition of dissolved carbonate minerals is accompanied—and usually triggered—by release of some of the carbon as CO_2. In many karst locations, CO_2 emission is associated with the deposition of calcareous sinter (tufa, travertine) at the outlet of cold or warm springs.

Though most abundant in humid regions, karst can also be found in arid terrains where H_2S in groundwater rising from reducing zones at depth oxidizes to produce sulphuric acid, which can form large caves, such as the Carlsbad Caverns of New Mexico. Similar processes also operate in humid regions but tend to be masked by the CO_2 reaction. Sulphates and rock salt are rarely exposed in humid climates. They are susceptible to rapid dissolution during periodic rains where they are at the surface in drier terrains.

Significance: Karst systems are sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, instability of overlying soils, and difficulty in designing effective monitoring systems around waste facilities. Instability of karst surfaces causes damage to roads, buildings and other structures. Radon levels in karst groundwater tend to be high in some regions, and underground solution conduits can distribute radon unevenly throughout a particular area.

Human Influence: Natural karst processes can be influenced by human activities such as land-use modification (e.g, deforestation), waste disposal, and opening or blocking of cave entrances, all of which can substantially affect sedimentation, speleothem deposition, and groundwater quality over the short term. Although most sinkhole collapse is triggered by high discharge of underground streams, lowering of water tables by overpumping in areas underlain by thick soils or weak rocks can induce ground failure and collapse into subsurface voids.

Lake levels and salinity

Brief Description: Lakes are dynamic systems that are sensitive to local climate and to land-use changes in the surrounding landscape [see shoreline position]. Some lakes receive their water mainly from precipitation, some are dominated by drainage runoff, and others are controlled by groundwater systems. On a time scale ranging from days to millennia, the areal extent and depth of water in lakes are indicators of changes in climatic parameters such as precipitation, radiation, temperature, and wind speed. Lake level fluctuations vary with the water balance of the lake and its catchment, and may, in certain cases, reflect changes in shallow groundwater resources.

Especially useful as climatic indicators are lakes without outlets (endorheic). In arid and semi-arid areas, the levels and areas of lakes with outflows are also highly sensitive to weather. Where not directly affected by human actions, lake level fluctuations are excellent indicators of drought conditions. Ephemerally- or seasonally-flooded lake basins (playas) are dynamic landforms, the physical character and chemical properties of which reflect local hydrologic changes, and which react sensitively to short-term climate changes (e.g., rate of evaporation). Fluctuations in lake water salinity also provide an indication of changes in conditions at the surface (climate, inflow/outflow relations) and in shallow groundwater [see sediment sequence and composition; surface water quality].

Significance: The history of fluctuations in lake levels provides a detailed record of climate changes on a scale of a decade to a million years. Lakes can also be valuable indicators of near-surface groundwater conditions.

Human Influences: Lake levels can be influenced by human-induced climate change, and by engineering works, such as dams and channels. Less drastic actions can also influence lake levels, for example, North Bar Lake in Sleeping Bear Dunes National Seashore, is an embayment lake that is being "loved to death." Historically, the lake was directly connected to Lake Michigan by an outlet channel. Heavy foot traffic has removed natural vegetation and destabilized the dunes near the lake. Increased sand transport from the dunes has filled in the outlet channel closing off the embayment lake, and, as a result, the embayment lake has lost its natural lake level fluctuation.

Relative sea level

Brief Description: The position and height of sea relative to the land (relative sea level - RSL) determines the location of the shoreline [see shoreline position]. Though global fluctuations in sea level may result from the growth and melting of continental glaciers, and large-scale changes in the configuration of continental margins and ocean floors, there are many regional processes that result in rise or fall of RSL that affect one coastline and not another. These include: thermal expansion of ocean waters, changes in meltwater load, crustal rebound from glaciation, uplift or subsidence in coastal areas related to various tectonic processes (e.g., seismic disturbance and volcanic action), fluid withdrawal, and sediment deposition and compaction. RSL variations may also result from geodetic changes such as fluctuations in the angular velocity of Earth or polar drift.

Significance: Changes in RSL may alter the position and morphology of coastlines, causing coastal flooding, waterlogging of soils, and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce salt-water intrusion into aquifers, leading to salinization of groundwater. Coastal ecosystems are bound to be affected, for example, by increased salt stress on plants. A changing RSL may also have profound effects on coastal structures and communities. Low-lying coastal and island states are particularly susceptible to sea-level rise.

Human Influences: Human actions including drainage of wetlands, withdrawal of groundwater (which eventually flows to the sea), and deforestation (which reduces terrestrial water storage capacity) may contribute to global rise in sea level. Human-induced climate change is also of obvious importance. Large engineering works, such as river channeling or dam construction, that influence sediment delivery and deposition in deltaic areas may cause local changes.

The big question in Cape Cod is whether the marshes can keep up with sea-level rise. Cape Cod's fresh groundwater rests on seawater and necessarily rises along with sea level; therefore, the diked Pamet marsh, for example, continues to rise along with groundwater levels, but in a way that is very different from the way salt marshes normally grow. Salt marshes typically keep pace with sea-level-rise largely through the accumulation of inorganic sediment, i.e., sand, silt, and clay. The diked upper Pamet has been denied this sediment supply for over 100 years. In the meantime, any accretion has been through the production of organic matter.

Sediment sequence and composition

Brief Description: Lakes, wetlands, streams (and overbanks), estuaries, reservoirs, fjords, shallow coastal seas, and other bodies of marine or fresh water commonly accumulate deposits derived from bedrocks, soils, and organic remains within the drainage basin, though fine particles can also be blown in by winds from distant natural, urban, and industrial sources. These aquatic deposits may preserve a record of past or on-going environmental processes and components, both natural and human-induced, including soil erosion [see soil and sediment erosion; wetlands extent, structure and hydrology], air-transported particulates [see dust storm magnitude, duration and frequency], solute transport, and landsliding [see slope failure]. Some of these bodies of water are dynamic and sensitive systems whose sedimentary deposits preserve in their chemical, physical, and biological composition a chronologically ordered and resolvable record of physical and chemical changes through their mineralogy, structure, and geochemistry [see surface water quality]. Of particular value in determining long-term data on water chemistry are the remains of aquatic organisms, which can be correlated with various environmental parameters. In addition, fossil pollen, spores, and seeds reflect past terrestrial and aquatic vegetation. Sediment deposits can, thus, provide an indication of the degree and nature of impact of past events on the system, and a baseline for comparison with contemporary environmental change. Some lakes (and reservoirs) are open systems characterized by relatively stable shorelines and a limited residence time for solutes; others are closed (endorheic) and/or ephemeral (playas).

Significance: The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

Human Influence: Sediment deposition is a natural process that can be strongly influenced by human activities (e.g., land clearing, agriculture, deforestation, acidification, eutrophication, industrial pollution) within the drainage basin or sediment catchment.

George Washington Birthplace National Monument (GEWA), specifically the Popes Creek watershed, serves as a reference system for environmental studies in the Chesapeake Bay region. Sediment sequences have recorded the history of farming and development beginning in colonial times. The farming activities and development in the Popes Creek Watershed occurred at a much lower level than similar coastal plain watersheds in the area. The sediment sequence in Popes Creek watershed, which is geologically similar to other systems in the Chesapeake Bay region, has provided baseline information for the studies that examine the affects of human activities on natural processes.

Seismicity

Brief Description: Crustal movements along strike-slip, normal, and thrust faults cause shallow-focus earthquakes (those with sources within a few tens of kilometers of Earth's surface), though they can also be human-induced. They can result in marked temporary or permanent changes in the landscape, depending on the magnitude of the earthquake, the location of its epicenter, and local soil and rock conditions [see surface displacement]. Deep-focus earthquakes (below about 70 km), unless of the highest magnitude, are unlikely to have serious surface manifestations.

To avoid, reduce, or warn of environmental impacts, it is necessary to know the size, location, and frequency of seismic events. These parameters can identify active faults and the sense of motion along them. Also of great importance is the spatial pattern of seismicity, including the presence of seismic gaps, and the relationship to known faults and active volcanoes. At least three, and generally many more, monitoring sites are required to determine the necessary parameters.

Seismic observations constitute one of the oldest forms of systematic monitoring of earth processes. There are now in operation many national, regional, and international seismic networks, which provide information about the location, size, and motion of earthquakes anywhere in the world. However, shallow-focus tremors of lower magnitude, may not be detected by these means, and must be monitored more closely, on a local basis. Seismic hazard maps can be constructed to identify areas at varying risk from earthquake damage.

Significance: Earthquakes constitute one of the greatest natural hazards to human society. Surface effects include uplift or subsidence, surface faulting, landslides and debris flows, liquefaction, ground shaking, and tsunamis ("tidal" waves caused by undersea tremors). Damage to buildings, roads, sewers, gas and water lines, power and telephone systems, and other built structures commonly occur.

Human Influence: Earthquakes are predominantly natural events. However, shallow-focus seismic tremors can be induced by human actions that change near-surface rock stresses or fluid pressures. These actions include: extracting or injecting water, gas, petroleum, or waste fluids into the ground for storage or for secondary hydrocarbon recovery; mining or quarrying activities; and loading the surface with large water bodies (reservoirs). Underground explosions, particularly for nuclear testing, can also generate seismic events. Deep injection of water at the Potash Mine on the boundary of Canyonlands National Park is known to induce earthquakes.

Shoreline position

Brief Description: The position of the shoreline along ocean coasts and around inland waters (lakes) varies over a broad spectrum of time scales in response to shoreline erosion (retreat) or accretion (advance), changes in water level, and land uplift or subsidence [see relative sea level; surface displacement]. Long-term trends in shoreline position may be masked in the short term by variations over periods of days to years, related, for example, to individual storms, changes in storminess, and El Niño/Southern Oscillation effects. Shoreline position reflects the coastal sediment budget, and changes may indicate natural or human-induced effects alongshore or in nearby river catchments. The detailed shape and sedimentary character of a beach (e.g. beach slope, cusp dimensions, bar position and morphology, barrier crest and berm elevation, sediment size and shape) are highly sensitive to oceanographic forcing, including deep-water wave energy, nearshore wave transformation, wave setup, storm surge, tides, and nearshore circulation: morphodynamic adjustments and feedbacks are common. Qualitative assessments of shoreline morphology can be used as a proxy for shore-zone processes, partially substituting for more quantitative measures of shoreline change where these are not available.

Significance: Changes in the position of the shoreline affect transportation routes, coastal installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal settlements to know if local shorelines are advancing, retreating, or stable.

Human Influence: Erosion and sediment accretion are on-going natural processes along all coasts. Human activities (e.g., dredging, beach mining, river modification, installation of protective structures such as breakwaters, removal of backshore vegetation, reclamation of nearshore areas) can profoundly alter shoreline processes, position and morphology, in particular by affecting the sediment supply.

In Fire Island National Seashore, a groin was installed to protect a water tower at Ocean Beach from erosion by currents, tides, and waves. The effect of the groin was to cause accelerated erosion downshore. This retreat of shoreline continued to migrate downshore through the barrier island system at a rate of one kilometer per year, holding the shape of an eight-foot scarp in the sand. Rough calculations estimate human-induced changes to the shoreline position amount to approximately two meters of beach recession in the last 45-50 years.

Slope failure

Brief Description: There are many ways in which slopes may fail, depending on the angle of slope, the water content, the type of earth material involved, and local environmental factors such as ground temperature. Slope failure may take place suddenly and catastrophically or may be more gradual. Slope failure results in landslides, debris and snow avalanches, lahars, rock falls, flows (debris, quick clay, loess, and dry or wet sand and silt), slides (debris, rock), topples, slumps (rock, earth), and creep.

Special conditions and processes exist in permafrost terrains. Landslides and mudflows of permafrost regions are mobilized and shaped by the freezing and thawing of pore water in the active layer, the base of which acts as a shear discontinuity. Failure here can occur on slopes as low as 1°. Gelifluction (a form of solifluction, the slow downslope movement of waterlogged soil and surficial debris) is the regular downslope flow or creep of seasonally frozen and thawed soils. Gentle to medium slopes with blankets of loose rock fragments overlying frozen ground may be subject to mass movements such as rock glaciers and rock streams or kurums [see frozen ground activity]. Catastrophic slope failure here can expose new frozen ground, setting off renewed mass wasting.

Three parameters are particularly important for monitoring all kinds of mass movements.

1. **Ground cracks** are the surface manifestation of a variety of mass movements. In plan, they are commonly concentric or parallel, and have widths of a few centimeters and lengths of several meters, which distinguishes them from the much shorter desiccation cracks [see desert surface crusts and fissures]. The formation of cracks and any increase in their rate of widening is a common measure of impending slope failure.
2. The appearance of and increases in **ground subsidence or upheaval** is also a good measure of impending failure.
3. The **area of slope failure** is a measure of the extent of landsliding in any region. Changes over time may both reflect significant environmental stresses (e.g., deforestation, weather extremes) and provide important clues about landscape and ecosystem degradation.

Climate change may accelerate or slow the natural rate of slope failure, through changes in precipitation or in the vegetation cover that binds loose slope materials. Wildfires can also promote mass movements by destroying tree cover. However, it is difficult to generalize where information is lacking on the present distribution and significance of landslides because many parameters, in addition to climate change, contribute to slope stability.

Significance: Slope failure causes death and property damage. Damage to ecosystems has not generally been documented, but landslides may destroy habitats, for example by blocking streams and denuding slopes.

Human Influence: Slope failure is a natural process that may be induced, accelerated, or retarded by human actions. Human influences include:

1. **Removal of lateral support** through human actions such as cutting slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs.
2. **Adding weight** to slopes by human actions such as landfills, stockpiles of ore or rock, waste piles, construction of heavy building and other structures, fill, and retaining walls.
3. **Vibrations** from explosions, machinery, road and air traffic.
4. **Decrease of underlying support** through mining.
5. **Lubricating slope materials** with water leaking from pipelines, sewers, canals, and reservoirs.

The Grand Ditch in Rocky Mountain National Park is a 16.2-mile aqueduct that diverts water from the West Slope streams to farms, ranches, towns, and cities on the eastern plains. Completed in 1936, it is one of the earliest transmountain diversions in Colorado. The Grand Ditch, which is cut into the mid- to upper slopes of the Never Summer Mountains, causes landslides in the upper Colorado River from undercutting the hillslope. Landslide material deposited in the Grand Ditch is side cast by bulldozers downslope when the ditch is cleaned annually.

<u>Soil and sediment erosion</u>

Brief Description: Erosion—the detachment of particles of soil and surficial sediments and rocks—occurs by hydrological (fluvial) processes of sheet erosion, rilling and gully erosion, and through mass wasting and the action of wind [see sediment geochemistry and stratigraphy; stream sediment storage and load; wind erosion]. Erosion, both fluvial and eolian (wind), is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance, erosion may increase greatly above natural rates. In uplands, the rate of soil and sediment erosion approaches that of denudation (the lowering of Earth's surface by erosional processes). In many areas, however, the storage of eroded sediment on hillslopes of lower inclination, in bottomlands, and in lakes and reservoirs, leads to rates of stream sediment transport much lower than the rate of denudation.

When runoff occurs, less water enters the ground, thus reducing plant productivity. Soil erosion also reduces the levels of the basic plant nutrients needed for growth, and decreases the diversity and abundance of soil organisms. Stream sediment degrades water supplies for municipal and industrial use, and provides an important transporting medium for a wide range of chemical pollutants that are readily sorbed on sediment surfaces. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals, and fish.

Significance: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems.

Human Influences: Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (ploughing, irrigation, grazing), forestry, construction, surface mining, and urbanization. Humans induce both water and wind erosion, which may result in chemical and physical deterioration of soil [see soil quality].

Within Sleeping Bear Dunes National Seashore, there are 11 major gravel and sand extraction pits or topsoil mining sites. The largest site is a 65-acre topsoil-mining site (STAN site); another site covers 40 acres on Scenic Drive.

<u>Soil quality</u>

Brief Description: Soils vary greatly in time and space. Over time-scales relevant to geoindicators, they have both stable characteristics (e.g., mineralogical composition and relative proportions of sand, silt, and clay) and those that respond rapidly to changing environmental conditions (e.g., ground freezing). The latter characteristics include soil moisture and soil microbiota (e.g., nematodes, microbes), which are essential to fluxes of plant nutrients and greenhouse gases. The soils of boreal regions are estimated to hold the equivalent of some 60% of the current atmospheric carbon: long-term warming is expected to increase decomposition and drying, thus potentially releasing huge volumes of methane and CO_2.

Most soils resist short-term climate change, but some may undergo irreversible change such as lateritic hardening and densification, podsolization, or large-scale erosion. Soil properties and climatic variables such as mean annual rainfall and temperature can be related by mathematical functions known as climofunctions.

Chemical degradation takes place because of depletion of soluble elements through rainwater leaching, overcropping and overgrazing, or because of the accumulation of salts precipitated from rising groundwater or irrigation schemes. It may also be caused by sewage containing toxic metals, precipitation of acidic and other airborne contaminants, as well as by persistent use of fertilizers and pesticides. A widespread problem is the retention in the soil organic matter and clay minerals of potentially toxic metals and radionuclides (e.g., Cu, Hg, Pb, Zn, ^{226}Ra, ^{238}U). These and other chemical components may be catastrophically released as what are commonly referred to as “chemical time bombs” where the pH of the soil is decreased by acidification or where other environmental disturbances (e.g., erosion, drought, land use change) intervene. Soils also act as a primary barrier against the migration of organic contaminants into groundwater. Key indicators are pH, organic matter content, sodium absorption ratio, cation exchange capacity, and cation saturation.

Physical degradation results from land clearing, and erosion and compaction by machinery. Soil structure may be altered so that infiltration capacity and porosity are decreased, and bulk density and resistance to root penetration are increased. Such soils have impeded drainage and are quickly saturated: the resultant runoff can cause accelerated erosion and transport of pollutants such as pesticides [see soil and sediment erosion]. The key soil indicators are texture (especially clay content), bulk density, aggregate stability and size distribution, and water-holding capacity.

Significance: As one of Earth’s most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of the land. Soils buffer and filter pollutants; they store moisture and nutrients; and they are important sources and sinks for CO_2, methane, and nitrous oxides. Soils are a key system for the hydrological cycle [see groundwater chemistry in the unsaturated zone]. Soils also provide an archive of past climatic conditions and human influences.

Human Influences: Soils may be degraded or enhanced by both natural processes and human activities. Human activities influence soil properties by causing increases in bulk density from agricultural tillage and road operations and in acidification from inorganic fertilizers and acid rain. Soil degradation is one of the largest threats to environmental sustainability.

Streamflow

Brief Description: Streamflow varies with the volume of water, precipitation, surface temperature, and other climatic factors. For most streams (rivers), the highest water discharge is found close to the sea, but in arid regions discharge decreases naturally downstream. Land use in drainage basins also strongly affects streamflow. Major streamflow regimes include glacial, nival, dry tropical, monsoon, equatorial, and desert. Reversals in streamflow, in conjunction with indirect methods of paleoflood studies and paleohydrology, yield long-term indicators of changes in discharge that are valuable for responses to flooding, estimating long-term trends in water and sediment discharges, and for distinguishing possible long-term climate change.

Significance: Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

Human Influences: Natural variations in streamflow predominate, but they can be strongly modified by human actions, such as dams and reservoirs, irrigation, and diversion for use outside the watershed.

Only two perennial streams, Leach and Little Cottonwood Creeks, are present in Craters of the Moon National Monument. These streams drain the Pioneer Mountains in the north end of the park. Diversion of streamflow in Little Cottonwood Creek began in the 1930s for park operations. Water demand was low until the late 1950s when the visitor center complex was built. It is estimated that peak consumption occurred in the late 1960s when over 50% of the streamflow was diverted out of the channel. At present (2000) this use has decreased to approximately 30% due to the reduction in the area of irrigated lawns.

Stream channel morphology

Brief Description: Alluvial streams (rivers) are dynamic landforms subject to rapid change in channel shape and flow pattern. Water and sediment discharges determine the dimensions of a stream channel (width, depth, and meander wavelength and gradient). Dimensionless characteristics of stream channels and types of pattern (braided, meandering, straight) and sinuosity are significantly affected by changes in flow rate and sediment discharge, and by the type of sediment load in terms of the ratio of suspended to bed load [see stream sediment storage and load]. Dramatic changes in stream bank erosion within a short time period indicate changes in sediment discharge.

Significance: Channel dimensions reflect magnitude of water and sediment discharges. In the absence of hydrologic and streamflow records, an understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, place significant limits on land use, such as on islands in braided streams and meander plains, or along banks undergoing erosion.

Human Influences: Significant changes in stream dimensions, discharge, and pattern may reflect human influences such as water diversion and increased sediment loads resulting from land clearance, farming, or forest harvesting. Such variations are also responsive to climatic fluctuations and tectonics.

Only two perennial streams, Leach and Little Cottonwood Creeks, are present in Craters of the Moon National Monument. There is evidence that the lower portion of Little Cottonwood Creek was historically diverted out of its natural channel. The creek makes a 90º bend, and a line of dead cottonwood trees and a ground depression indicate where the channel used to be. The channel morphology of Leach Creek has also been altered. There are old impoundments or control structures in the upper portion of the creek. A dry channel in the lower portion indicates that the creek was historically diverted out of its natural channel. Both creeks continue to be diverted out of their original channels (2000).

Stream sediment storage and load

Brief Description: The load (discharge, tonnes/year) or yield (tonnes/km2/year) of sediment (in suspension and as bed load of sand and gravel) through stream (river) channels reflects upland erosion within the drainage basin and change in storage of sediment in alluvial bottomlands [see soil and sediment erosion]. In turn, climate, vegetation, soil and rock type, relief and slope, and human activities such as timber harvesting, agriculture, and urbanization influence stream sediment storage and load. Much of the sediment eroded from upland areas is deposited (stored) on lower hillslopes, in bottomlands, and in lakes and reservoirs. Flash floods in ephemeral desert streams may transport very large sediment loads, accounting for unforeseen sedimentation problems in dryland stream reservoirs.

Significance: Sediment load determines channel shape and pattern [see stream channel morphology]. Changes in sediment yield reflect changes in basin conditions, including climate, soils, erosion rates, vegetation, topography, and land use. Fluctuations in sediment discharge affect a great many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load. For example, to reproduce effectively, salmon and trout need gravel stream beds for spawning and egg survival; silt and clay deposits formed by flooding or excessive erosion can destroy these spawning beds. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

Human Influences: Stream sediment storage and load is influenced strongly by human actions, such as in the construction of dams and levees, forest harvesting, and farming in drainage basins.

Subsurface temperature regime

Brief Description: Temperatures in boreholes a few hundred metres deep can be an important source of information on recent climatic changes because the normal upward heat flow from Earth's crust and interior is perturbed by the downward propagation of heat from the surface. As temperature fluctuations are transmitted downward, they become progressively smaller, with shorter-period variations attenuating more rapidly than longer ones. Although seasonal oscillations may be undetectable below about 15 m, century-long temperature records may be observed to depths of 150 m or so. Bedrocks thus selectively retain the long-term trends required for reconstructing climate change.

The surface temperature is strongly affected by local factors such as thickness and duration of snow cover, type of vegetation, properties of organic soil layers, depth to the water table, and topography. It influences, in turn, a wide range of ground and surface processes, particularly in the near-surface portions of permafrost [see frozen ground activity]. Below the active layer, where ground temperature fluctuates seasonally as thawing and freezing take place, long-term temperature variations may be recorded. Here, repeated measurements of soil temperature at fixed locations can reveal both the long-term dynamics of seasonally frozen ground and long-term climatic fluctuations, though the conversion of ground temperature to climate history is a complex matter.

Significance: The thermal regime of soils and bedrocks exercises an important control on the soil ecosystem, on near-surface chemical reactions (e.g., involving groundwater), and on the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity, and decay of plants; the availability and retention of water; the rate of nutrient cycling; and the activities of soil microfauna. It is also of major importance as an archive of climate change, indicating changes in surface temperature over periods of up to 2-3 centuries, for example in regions without a record of past surface temperatures. In permafrost, the ground temperature controls the mechanical properties of the soils, especially during the freeze-thaw transition in the active layer.

Human Influence: The subsurface temperature regime reflects both the natural geothermal flux from Earth's interior and the surface temperature. The latter can be modified by human actions, such as land clearing, wetland destruction, agriculture, deforestation, flooding of land for reservoirs, or development of large settlements that give rise to a "heat island" effect.

Surface displacement

Brief Description: Earth's surface is subject to small but significant displacements (uplift, subsidence, lateral movement, rotation, distortion, dilation) that affect elevation and horizontal position. These movements result from active tectonic processes, collapse into underground cavities, or the compaction of surficial materials. Sudden movements may be caused by faulting associated with earthquakes [see seismicity], and from the collapse of rock or sediment into natural holes in soluble rocks (e.g., salt, gypsum, limestone) [see karst activity], or into cavities produced by mining of near-surface rocks (especially coal) and solution-mining of salt. Slower local subsidence may also be induced by: fluid withdrawal (gas, oil, groundwater, geothermal fluids); densification or loss of mass in peat being developed for agriculture; drainage of surface waters from wetlands, which can cause oxidation, erosion, and compaction of unconsolidated soils and sediments [see wetlands extent, structure and hydrology]; and filtration of surface water through porous sediments such as loess. On a much larger scale, the land surface elevation responds slowly to plate movements, compaction of sedimentary basins, and glacial rebound.

Fissures and faults can develop suddenly during earthquakes and as a result of volcanic processes and landsliding, or more slowly as a result of differential compaction during subsidence. In arid and semi-arid terrains, fissures up to several kilometers long and a few centimeters wide may be rapidly eroded by surface run-off to gullies.

Significance: Most surface displacements have but minor effects on landscapes and ecosystems. However, there are exceptions, such as where drainage channels are suddenly displaced by faults, or where seismically-induced uplift raises intertidal ecosystems above sea level. Moreover, extraction of fluids beneath urban areas can induce land subsidence and cause flooding, especially of coastal communities near sea-level. Subsidence damages buildings, foundations, and other built structures.

Human Influence: Surface displacements are natural phenomena associated with plate movements, glacial rebound, and faulting, but human activities such as extraction of groundwater, oil, and gas can also induce surface subsidence.

In Cape Cod National Seashore, surface displacement is linked to other geoindicators—relative sea level and wetlands. Ditching and diking of formerly tidal wetlands have caused significant subsidence within the Seashore. The subsidence is significant not with respect to aerial extent, but to the sensitivity of habitats affected and the challenge subsidence poses to restoration efforts.

Surface water quality

Brief Description: The quality of surface water in rivers and streams, lakes, ponds, and wetlands is determined by interactions with soil, transported solids (organics, sediments), rocks, groundwater, and the atmosphere. It may also be significantly affected by agricultural, industrial, mineral and energy extraction, urban and other human actions, as well as by atmospheric inputs. The bulk of the solutes in surface waters, however, are derived from soils and groundwater baseflow where the influence of water-rock interactions are important [see groundwater quality; karst activity; soil and sediment erosion; soil quality; streamflow; wetlands extent, structure, and hydrology].

Significance: Clean water is essential for the survival of all forms of life. Most is used for irrigation, with lesser amounts for municipal, industrial, and recreational purposes: only 6% of all water is used for domestic consumption. Pathogens such as bacteria, viruses, and parasites are among the world's most dangerous environmental pollutants and cause water-borne diseases. Water quality data are essential for the implementation of responsible water quality regulations, for characterizing and remediating contamination, and for the protection of the health of humans and other organisms.

Human Influence: The water quality of a lake, reservoir, or river can vary in space and time according to natural morphological, hydrological, chemical, biological, and sedimentological processes (e.g., changes of erosion rates). Pollution of natural bodies of surface water is widespread because of human activities, such as disposal of sewage and industrial wastes, land clearance, deforestation, use of pesticides, mining, and hydroelectric developments.

Trespass cattle at springs in Arches National Park raise a concern regarding maintenance of good water quality. Impacts include trampled soil and vegetation, increased sedimentation, and elevated levels of fecal contamination.

Herbicides to decrease the number of tamarisk stands may cause water quality problems associated with streams and springs in Arches National Park, Canyonlands National Park, and Natural Bridges National Monument.

Volcanic unrest

Brief Description: Eruptions are almost always preceded and accompanied by volcanic unrest, indicated by variations in the geophysical and geochemical state of the volcanic system. Such geoindicators commonly include changes in seismicity, ground deformation, nature and emission rate of volcanic gases, fumarole and/or ground temperature, and gravity and magnetic fields. Volcanic unrest can also be expressed by changes in temperature, composition, and level of crater lakes, and by anomalous melting or volume changes of glaciers and snow fields on volcanoes. When combined with geological mapping and dating studies to reconstruct comprehensive eruptive histories of high-risk volcanoes, these geoindicators can help to reduce eruption-related hazards to life and property. However, not all volcanic unrest culminates in eruptions; in many cases the unrest results in a failed eruption in which the rising magma does not breach the surface and erupt.

Significance: Natural hazards associated with eruptions pose a significant threat to human and animal populations. Before 1900, two indirect hazards—volcanogenic tsunamis and post-eruption disease and starvation—accounted for most of the eruption-associated human fatalities. In the 20th century, however, direct hazards related to explosive eruptions (e.g., pyroclastic flows and surges, debris flows, mudflows) were the most deadly hazards.

Human Influence: None. Volcanism is a natural process which has operated since the formation of Earth. Although a few attempts have been made to divert lava flows, humans have had no influence whatsoever on the underlying causes of volcanism.

Wetlands extent, structure, and hydrology

Brief Description: Wetlands are complex and sensitive ecosystems, characterized by a water table at or near the land surface for some part of the year, by soil conditions that differ from adjacent uplands, and by vegetation adapted to wet conditions. Wetlands are usually classified on the basis of their morphology and vegetation and, to a lesser extent, their hydrology. Though definitions vary, the following types are widely recognized: coastal salt and freshwater marshes; swamps (mangrove, shrub, and wooded); wet grasslands, meadows and prairies; and peatlands (landforms in which organic sediments have accumulated to depths in excess of 30-50 cm, including mires, moors, muskeg, bogs, and fens).

The areal extent, distribution, and surface and internal structures of a wetland can be altered by many processes, such as organic and inorganic sediment deposition and erosion, paludification (lateral spread), terrestrialization (colonization of open water by wetland plant communities), and changing hydrology. In the case of coastal wetlands, saltwater intrusion and changes in sea level can also be important [see relative sea level, shoreline position].

Hydrological relationships play a key role in wetland ecosystem processes, and in determining structure and growth. Different wetlands have a characteristic hydroperiod, or seasonal pattern of water levels, that defines the rise and fall of surface and subsurface water. An important geoindicator is the water budget of a wetland, which links inputs from groundwater, runoff, precipitation, and physical forces (wind, tides) with outputs from drainage, recharge, evaporation, and transpiration. Annual or seasonal changes in the range of water levels affect visible surface biota, decay processes, accumulation rates, and gas emissions. Such changes can occur in response to a range of external factors, such as fluctuations in water source (river diversions, groundwater pumping), climate or land use (forest clearing). Waters flowing out of wetlands are chemically distinct from inflow waters, because a range of physical and chemical reactions take place as water passes through organic materials, such as peat, causing some elements (e.g., heavy metals) to be sequestered and others (e.g., DOC, humic acids) to be mobilized. A baseline of wetland conditions may be established through a paleoecological study to investigate whether a present-day wetland is stable or actively evolving, and if so in what direction and at what rate.

Significance: Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands mediate large and small-scale environmental processes by altering downstream catchments. The dissolved carbon burden of wetlands may affect downstream waters, for example by acid drainage. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants, such as Hg, and serving as flood buffers and, in coastal zones, as storm defenses and erosion controls.

Wetlands can act as carbon sinks, storing organic carbon in waterlogged sediments. Even slowly growing peatlands may sequester carbon at between 0.5 and 0.7 tonnes/ha/yr. Wetlands can also be a carbon source, when it is released via degassing during decay processes, or after drainage and cutting, as a result of oxidation or burning.

Human Influence: Wetlands develop naturally in response to morphological and hydrological features of the landscape. Their evolution can be affected by external factors such as climate change, landscape processes (e.g., coastal erosion), or human activity (draining, channeling of local rivers, water abstraction and impoundment, forest clearance). Wetlands can be lost to drainage for agriculture or settlement or to harvesting for commercial purposes.

Diking and drainage in the late 19th century and freshwater impoundment in the mid-20th century have interrupted the evolution of salt marshes in the upper Pamet River in Cape Cod National Seashore. These hydrologic alterations have caused vegetation to shift from salt-tolerant grasses to salt-intolerant herbs, trees, and shrubs and have caused the wetland surface to subside well below the elevation of modern, undiked marshes.

Wind erosion

Brief Description: The action of wind on exposed sediments and friable rock formations causes erosion (abrasion) and entrainment of sediment and soil particles [see dust storm magnitude, duration and frequency]. Eolian action also forms and shapes sand dunes, yardangs (streamlined bedrock hills), and other landforms. Subsurface deposits and roots are commonly exposed by wind erosion. Wind can also reduce vegetation cover in wadis and depressions, scattering the remains of vegetation in interfluves. Stone pavements may result from the deflation (removal) of fine material from the surface leaving a residue of coarse particles. Blowouts (erosional troughs and depressions) in coastal dune complexes [see dune formation and reactivation] are important indicators of changes in wind erosion. The potential for deflation is generally increased by shoreline erosion or washovers, vegetation die-back (due to soil nutrient deficiency or to animal activity), and human actions such as recreation and construction.

Significance: Changes in wind-shaped surface morphology and vegetation cover that accompany desertification, drought, and aridification are important gauges of environmental change in arid lands. Wind erosion also affects large areas of croplands in arid and semi-arid regions, removing topsoil, seeds, and nutrients.

Human Influence: Eolian erosion is a natural phenomenon, but the surfaces it acts upon may be made vulnerable by human actions, especially those, such as cultivation and over-grazing, that result in the reduction of vegetative cover.

Currently in Cape Cod National Seashore (CACO), human actions [e.g., use of ORVs (off-road vehicles) and the proliferation of social trails] influence wind erosion. Degraded areas are limited, but it is of high management significance because of the impacts on popular areas, such as Herring Cove. Aerial photographs revealed a “spider web” of social trails in this area.

Appendix B: Human Influences

The term "human influences" is the central theme for the second part of GPRA goal Ib4. The term has purposefully been selected in order to explore the full breath of human activities, both inside national parks and external to the park boundaries. Adjacent land use, consumptive activities, administrative practices, and public visitation can all influence earth surface processes. An effective way to illustrate human influences on earth surface processes is to go through some examples. This is not a comprehensive treatment, and these examples do <u>not</u> occur in all parks. These examples are provided to raise awareness, stimulate the reader's thinking, and perhaps cause the reader to contemplate additional cases from his or her own experience.

Land Use

Agriculture – Intense use can cause loss of soil, erosion, and dust storms. Use of pesticides can affect both surface water and groundwater quality.

Grazing – Overgrazing can cause loss of vegetation, invasion of exotic species, soil erosion, and nutrient loss.

Forestry – Intensive logging or clear cutting creates conditions for increased erosion; eroded and transported sediment can cause increased sediment loading in streams, which could affect fluvial habitat.

Water impoundment – This has the potential to affect one segment of a stream or river or an entire watershed. Controlled volume of flow does not duplicate natural events, such as floods and drought. It can affect the sediment load, change the stream morphology, and alter the habitat that is dependent on a fluvial system.

Urbanization – This can cause a host of impacts, but a few stand outs are: change in drainage patterns because of impervious surfaces (streets, parking lots, pavement, buildings), increased erosion, affects on surface and groundwater quality and quantity, release of toxins into the air, increased humidity in arid regions.

Alterations to shorelines – Dredging, beach mining, river modification, installation of protective structures, and removal of back-shore vegetation can potentially alter shoreline processes, position, and morphology by changing the sediment supply, transport, and erosion.

Consumptive Use

Groundwater withdrawal –This sustainable, renewable resource can become a non-renewable, mined one, if we withdraw groundwater faster than it is being recharged. Mining groundwater is terminal and affects and entire ecosystem (both living and non-living components). Where withdrawal has been intense for decades, the surface has been known to collapse (subside) over many acres to depths of over ten feet.

Oil and gas production – This can cause surface subsidence and contamination of water aquifers and cave & karst systems. Oil and gas operations can leave a considerable "footprint" on the land, such as roads (created during seismic tests and well operation), pipelines, facilities, storage tanks, and well pads.

Mining (open pit and underground) – It can reconfigure the landscape over large areas bringing significant and permanent change to the landscape. It can affect the groundwater by releasing heavy metals or other chemicals into the system.

Mineral Materials Mining – If performed in sensitive ecosystems or with respect to volume of material removed, the quarrying of stone, mining of gravel, and borrowing of soil can impact geologic process.

Extirpation of species – This can affect both the living and non-living components of an ecosystem. Take the elimination of beaver from an ecosystem, for example. This can alter water impoundment, sediment load, timing of sediment release, and stream channel morphology.

Administrative Use

Roads & bridges – Often these have been constructed with little or no consideration for natural processes. Roads can disrupt drainage, cause erosion, and create hillslope instability. The abutments for bridges can change the flow and morphology of streams and rivers.

Parking lots – Construction, location, and drainage off parking lots can cause harm. Large paved areas (acres) deprive the surface of an opportunity to absorb precipitation. Water flowing from the parking lots can cause erosion and gullying if not directed properly. Runoff pollution affects surface water and groundwater.

Facilities placed over karst and caves – Contaminants and runoff from restrooms and other water usage can reach cave and karst systems below the Earth's surface and cause damage to the fragile subterranean ecosystem.

Water consumption – Parks located in arid environments need special consideration for all aspects of water usage (restrooms, watering lawns, domestic use for staff, maintenance shops, etc.)

Trails – If they are poorly located with respect to soil, rockwalls, wetlands, and sensitive vegetation, they have the potential to exacerbate erosion, rock falls, and slope instability. The placement of snowmobile trails can influence slope stability and cause avalanches.

Armoring – Through engineering efforts, humans have attempted to impose stability on naturally dynamic and ever-changing environments along streams, rivers, coastlines, and shorelines. Structures interfere with the transport of sand and sediment and aggravate erosion over the long-term.

Planting exotic species – Planting non-native species on sand dunes to hold them in place disrupts aeolian processes that drive an ecosystem.

Fire – Fires directly affect slope stability and can cause debris flows on steep slopes.

Visitor Use

Compaction of soils – Over use by recreationists (hiking, horseback riding, mountain biking, OHV's) can compact soil, which diminishes its capability to function and maintain itself as a viable part of the ecosystem.

Social trails – Depending on the fragile nature of the environment, wandering off-trail can seriously damage fragile resources (in caves, wetlands, soil crusts, cinder cones, tundra, etc.)

Touching fragile features – A number of geologic features have taken years to form through geologic processes, and although seemingly rock-hard, they may be fragile. Examples include stalactites and stalagmites in caves. Also included are erosional features, such as arches, bridges, hoodoos, and badlands. Crystals are another example. Visitors touching or climbing on all these features can cause irreparable damage.

Power boating – Over a period of time, wakes from small and large boats alike can contribute to shoreline erosion. Fuel contamination can affect water quality.

Appendix C: Introducing Geoindicators

What are Geoindicators?

Geoindicators constitute an approach for identifying rapid changes in the natural environment. An international Working Group of the International Union of Geological Sciences (IUGS) developed geoindicators in order to access common geological processes occurring at or near Earth's surface that may undergo significant change in magnitude, frequency, trend, or rates, over periods of 100 years or less. Geoindicators measure both catastrophic events and those that are more gradual but evident within a human lifespan. Some geoindicators can provide a record of natural events through time.

The 27 geoindicators are:

28. Coral chemistry and growth patterns
29. Desert surface crusts and fissures
30. Dune formation and reactivation
31. Dust storm magnitude, duration, and frequency
32. Frozen ground activity
33. Glacier fluctuations
34. Groundwater quality
35. Groundwater chemistry in the unsaturated zone
36. Groundwater level
37. Karst activity
38. Lake levels and salinity
39. Relative sea level
40. Sediment sequence and composition
41. Seismicity
42. Shoreline position
43. Slope failure (landslides)
44. Soil and sediment erosion
45. Soil quality
46. Streamflow
47. Stream channel morphology
48. Stream sediment storage and load
49. Subsurface temperature regime
50. Surface displacement
51. Surface water quality
52. Volcanic unrest
53. Wetlands extent, structure, hydrology
54. Wind erosion

Why are Geoindicators important?

Ecosystem management, reporting, and planning generally focus on biological issues such as biodiversity, threatened and endangered species, exotic species, and biological and chemical parameters relating to pollution (e.g. air and water quality). Much less attention is paid to the physical processes that shape the landscape—the natural, changing foundation on which humans and all other organisms live and function.

Geoindicators help answer NPS resource management questions about what is happening to the environment, why it is happening, and whether it is significant. They establish baseline conditions and trends, so that human-induced changes can be identified. Applying the geoindicators approach will provide science-based information to support resource management decisions and planning. Geoindicators help non-geoscientists focus on key geological issues, help parks anticipate what changes might occur in the future, and identify potential management concerns from a geological perspective.

Geology and geological processes are integral to park management and planning. For example, the underlying geology and soil influence natural vegetation patterns, and in turn exert a control on biological communities. Geological processes can affect park roads, infrastructure, and facilities. When measures of natural landscape change are omitted from monitoring and planning, the assumption that natural systems are stable, fixed, and in equilibrium is perpetuated. Natural systems are dynamic, and some may be chaotic; change is the rule, not the exception. Monitoring the abiotic components of ecosystems using geoindicators will help to emphasize this point.

The geoindicators approach can be a useful reminder both of the prevalence of natural fluctuations and of the difficulty of separating them from human-induced environmental change. Using geoindicators shifts management actions from response (crisis mode) to long-range planning, so issues can be recognized before they become concerns. Geoindicators may also prove to be useful tools for enhancing interdisciplinary research and communication, a way to connect with others concerned with environmental issues and problems.

How do Geoindicators fit into the National Park Service's strategic plan?
In 1999, the NPS Geologic Resources Division (GRD) and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal as part of the Government Performance and Results Act (GPRA). The NPS Goal Ib4 states, "Geological processes in 75 parks (36% of 270 natural resource parks) are inventoried and human influences that affect those processes are identified." This goal was designed to increase understanding of geological processes and their functions in ecosystems and to help park managers make more informed science-based management decisions.

This goal is intended to be the first step in a process that will lead to inventory, monitoring, and research, and ultimately focus on the mitigation or elimination of human activities that severely impact geological processes, harm geologic features, or cause critical imbalance in ecosystems.

What is the purpose of a Geoindicators scoping meeting?
The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. Pertinent human influences may include visitor impacts, park management practices and developments, land use adjacent to parks (e.g. pollutants, timber harvest), and global issues (e.g. industrial dust from China).

In addition, resource management issues related to geology and geological processes will be identified; and inventory, monitoring, and research studies that can provide scientific data to be used in making management decisions will be recommended.

How does the Geoindicators scoping process work?
The GRD coordinates efforts between park resource managers and geologists (from federal and state agencies and academia) through scoping meetings that are held in national parks. The scoping meetings are designed to use the participants' expertise and knowledge and build on the synergy of the participants through field trips, group discussion, and the exchange of ideas. For park staff, the scoping meetings foster a better understanding of the physical resources and geological processes in the park. For scientists, the scoping meetings foster an awareness of management issues and the decision-making and planning processes preformed by park staff.

The field trip portion of a scoping meeting highlights the park's setting and geology, as well as key resource management issues related to geological processes. During the discussion portion of a scoping meeting, selected geoindicators—specific to a park's setting—guide and focus the dialog.

The following questions are addressed during the group discussion of a scoping meeting. The answers are rated and prioritized.

What are the significant geological processes in the park's ecosystems? Why are they significant?

Which of these geological processes is being influenced by human activities both from inside and outside the park?

How significant to park management are the identified geological processes and associated human influences?

What sort of geological baseline data would benefit the park?

What geoindicators should be monitored in the park? What protocols are recommended and who are the geoscientists to contact?

Where are the information gaps? What studies or research are recommended?

What are the outcomes of a Geoindicators scoping meeting?
Scoping meetings provide an opportunity for park staff and geologists to connect and build relationships. This is significant because many park managers do not have easy access to geological expertise, and most do not have geologists on staff or in their regional offices.

Managers from participating parks will receive a summary report that highlights the recommendations identified during the scoping meeting. Recommendations include inventory and monitoring—which will provide information to use for park planning and decision-making—and research topics that will fill information gaps.

Where can I get more information?
Web site about geologic resource monitoring in the U.S. National Parks:
http://www2.nature.nps.gov/grd/geology/monitoring/index.htm.

Detailed descriptions of the 27 geoindicators:
http://www2.nature.nps.gov/grd/geology/monitoring/parameters.htm.

Web site of the IUGS Geoindicators Initiative: http://www.lgt.lt:8080/geoin/welcome.

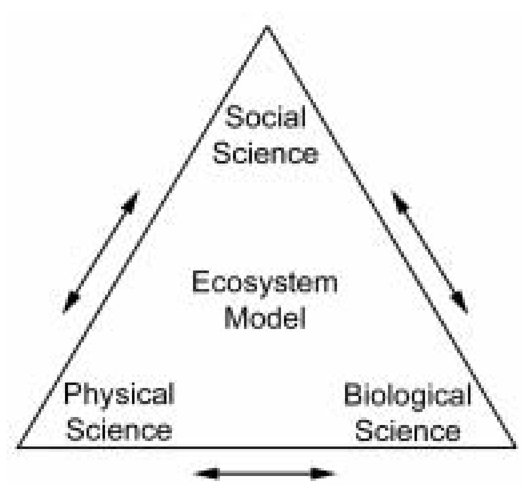
Appendix D: Species Don't Stand Alone—Geology's Role in Ecosystems

Ecology's fundamental insight for ecosystem management is that species do not stand alone. Organisms are dynamically and interactively enmeshed in the abiotic ecosystem matrix. Increasingly, ecologists and land-management agencies are recognizing that species—the living components of ecosystems—cannot be conserved without conserving the non-living components, which help shape ecosystem structure and function (Pickett et al., 1992; Christensen et al., 1996). As "matrix sciences," physical sciences such as geology, soil science, hydrology, and climatology play a fundamental role in conservation and ecosystem management.

The founder of modern ecosystem ecology was a soil scientist, Hans Jenny (Vitousek, 1994), and James Lovelock, a geophysicist, conceptualized Planet Earth as a functional ecosystem composed of functional subsystems (Rowe, 2001). Yet despite these historical connections between the sciences and the tremendous importance of the matrix sciences to ecosystem studies, most ecosystem mangers have not traditionally integrated the biological and physical sciences in resource management. The problem may be that most ecosystem managers/ecologists have been educated in biology departments and trained to focus on species (Rowe, 2001). Thus, the abiotic components of an ecosystem often enter management discussions as an afterthought, of secondary importance and vaguely associated with the fuzzy term "habitat," if they enter the discussion at all.

Over the last two decades, however, the focus of land management has slowly been shifting to a truly integrated, ecosystem approach—one that recognizes that species do not stand alone—and incorporates biological, geological, and social components (Figure 1). This change is particularly important as resource managers strive to gain greater predictive and mechanistic understanding of ecosystem responses to human activities. This approach identifies a need to devote increased attention to the geosciences, and especially to the interactions between the geological and biological systems.

Figure 1. Relationship of component parts to an ecosystem.



Geological processes create topographic highs and lows; impact water and soil chemistries; influence the fertility of soils, the stability of hillsides, and the flow styles of surface water and groundwater (Swanson et al., 1988). These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts. Likewise, biological processes affect geological processes. Biological activity contributes to soil formation and soil fertility, controls hillside erosion, traps blowing sand to form dunes, stabilizes drainages, and attenuates floods.

The geological resources of a park—soils, caves, glaciers, streams, springs, volcanoes, etc.—provide the physical foundations required to sustain the biological system. Human influences on geological processes and alteration of geological features inevitably affect habitat conditions. For example, the channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of floodplain obligate species (Smith, 1998; Steen, 1999). In Jean Lafitte National Historical Park and Preserve, externally triggered land subsidence is raising the water level in the park, thereby inundating the swamp forest and reducing habitat for forest-dependent species (Sauier, 1994). Alternatively, a manipulation of the biological system can trigger changes in the geological system that can re-affect the biological system. For example, when beaver are trapped to increase the density of hydrophobic shrub species, the river morphology and sediment transport capacity change, resulting in a redistribution of the types of fish species. Geological resources also influence the impacts of natural variation in factors such as climate or human activity. The availability of water, the stability of soil surfaces, and nutrient supply from weathering rocks are all examples of underlying physical controls on biological processes.

A challenge in appreciating the relevance of geology is that geologists often work with very long time scales; whereas, life-science specialists deal with much shorter time scales. In actuality, however, geological processes occur over a variety of temporal and spatial scales. At one end of the temporal spectrum lie the processes that occur over millions of years, such as the rising of a mountain range or creation of an ocean basin. At the other end lie the processes that occur virtually instantaneously (and often catastrophically) such as floods, landslides, and earthquakes. Between these extremes is the constant, continuous evolution of a landscape over days, months, and years. Examples of these are shoreline movement, river transport of sediment, soil formation, and cave development.

Geological processes are as diverse spatially as they are temporally. The absorption of chemical elements by sediment particles may be the key process in determining groundwater chemistries. This process occurs at the microscopic level. In contrast, the geothermal activity at Yellowstone or Lassen Volcanic national parks is related to the movement of tectonic plates at a global scale.

Geological processes that most directly impact biological processes include: stream and groundwater flow, weathering and mass wasting (e.g., landslides, rockfalls), earthquakes, volcanic phenomena (e.g., eruptions, hot springs), and variation in physical and biogeochemical attributes of soils. These processes collectively operate on a variety of time scales, and it is possible for all of these processes to be operating simultaneously in a single park. For example, minor earthquakes usually accompany eruptions in Hawaii Volcano National Park, and the overall event can include landslides, stream diversion by lava flows, and buildup of topography when the lava flows solidify. These processes destroy some habitats while creating others, and introduce new substrates for early successional stages, thus maintaining habitats for early successional species (Parrish and Turner, 2001).

Even seemingly static geological resources contribute to ecosystem mosaics and biodiversity. For example, in Grand Canyon National Park, the nesting sites of spotted owls are restricted to ledges formed in a specific rock layer, the Hermit Shale. Similarly, vegetation distributions in Canyonlands National

Park respond to variation in surface soil textures and elemental content. Thus, management of the nesting sites of threatened species and unique native plant habitats requires knowledge of the geological substrate. Identifying that a rock layer is important to an owl species indicates the need for integrated research. An example of floral dependence on geology is the Winkler's cactus, which grows only on the white, powdery soil and pebbles eroded from part of the Morrison Formation in Canyonlands National Park. In this case, not only is the distribution of the rock layer itself important to the plant, but the erosion products are quite fragile, requiring management of both the plant and its delicate habitat (Parrish and Turner, 2001). This same type of abiotic-biotic pattern repeats itself across the entire Colorado Plateau, a region recognized for its high frequency of plant endemism primarily because of the evolutionary constraints posed by extensive exposures of raw geologic substrates (Welsh et al., 1993).

Abiotic ecosystem components, encompassed by the matrix sciences, play central roles in shaping the distribution and dynamics of biotic systems. Nutrient constraints; water availability; disturbances in the form of landslides, floods, droughts, and eolian processes all act to constrain the composition, structure, and productivity of the terrestrial biosphere. These processes also influence the distribution of individual plant and animal species across the landscape and condition the responses of ecosystems to environmental change. In present-day ecosystems, there is tremendous variability across landscapes and through time in the ways that ecosystems respond to changes in species, climatic patterns, and land use; this variability is poorly understood. For example, how will ecosystems, and the goods and services they provide, be differentially affected by the numerous interacting components of global change: increased temperatures and CO_2 concentrations, altered precipitation patterns, and greater frequencies of extreme climatic episodes? This question can no longer be left to the future (McCarty, 2001; Hannah et al., 2002). From a management perspective it is crucial to identify and predict the spatial and temporal variation in both ecological vulnerabilities and services. Improved understanding of this variability would allow for more efficient, cost-effective, and sustainable use of natural resources. One of the primary hindrances to this understanding is the lack of integrative science that could facilitate ecological forecasting. In the face of rapid environmental changes, successful resource management cannot be accomplished without integrating the abiotic matrix sciences with the more-familiar biotic sciences.

These are exciting and stressful times for resource managers, as attempts to counter threats to cherished places and species are made. Disciplinary boundaries, although essential for some purely scientific tasks, are an impediment to understanding complicated issues such as preservation of ecosystems. Human attitudes and past human influences on natural systems are crucial elements in understanding what is happening and what options are available (Ludwig, 2001).

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Appendix E: Park Settings

All four parks are located in the high desert of southeastern Utah. The climate is one of very hot summers, cold winters, and very little rainfall. On a daily basis, temperatures may fluctuate as much as 50 degrees Fahrenheit. Afternoon thunderstorms occur frequently from about mid-July through late summer. Snow occasionally falls in winter, especially at the higher elevations of the parks.

Arches National Park

Arches has elevations ranging from 4,000 to 5,600 feet. The park contains the greatest density (over 2,000 cataloged arches) of natural arches in the world. Towering spires, fins, and balanced rocks complement the arches, creating a remarkable assortment of landforms in a relatively small area. The park has a diversity of plant and animal life that reflects the variety of habitats present in the area, including lush riparian areas, hanging garden seeps, ephemeral pools, dry arroyos, mixed grassland flats, sand dunes, and large expanses of bare rock.

The park also has significance cultural sites that document 10,000 years of human history in the area. The oldest sites consist of piles of chert and other flakes that represent knapping sites [Explain what these are.]. Some of the most significant are rock inscription panels left behind by ancestors of today's Pueblo people. The Fremont culture is also evident in the park, and existed at the same time as the ancestral Pueblo people. Fremont-style rock inscriptions, pottery and other artifacts document their presence. Both cultures of people left the area around 700 years ago.

Nomadic Ute and Paiute people entered the area in historic times and, like the Pueblo and Fremont left behind rock inscriptions, including the images near Wolfe Ranch that depict people on horseback.

Early European explorers included Spaniards, who passed through the area in the 1700s, following the route now used by the highway near the vicinity of the park visitor center. Mormons settled the area in the late 1800's, with Moab settled permanently starting in the 1880s. In 1898, John Wesley Wolfe built the homestead, known as Wolfe Ranch, in what is now the park.
In 1929, President Hoover designated the area as Arches National Monument. In 1971, Congress changed it to a national park.

Canyonlands National Park

Canyonlands preserves one of the last, relatively undisturbed areas of the Colorado Plateau. It is a landscape of canyons, mesas, and deep river gorges. Elevations in the park range from 3,700 to 7,200 feet.

The park has a diversity of plant and animal life that reflects the variety of habitats present in the area, including lush riparian areas, swift rivers, ephemeral pools, dry arroyos, mixed grassland flats, relict mesa tops, hanging garden seeps, and large expanses of bare rock.

People have visited what is now Canyonlands for over 10,000 years. Projectile points document occupation by Paleoindians, the first humans to inhabit the region. People routinely lived in the area beginning about 5,000 BC. Between that time and AD 250, Archaic rock-art panels of the "Barrier Canyon" style were produced. These can be seen in the Horseshoe Canyon, a detached unit of the park.

By A.D. 1200 there was a major occupation in the Salt Creek Canyon drainage (Needles District), and scattered occupation throughout the rest of the park, by Ancestral Puebloan people. Storage structures, granaries, pottery, tools and rock art document their presence. By AD 1300, they had left the region and moved south to Arizona and New Mexico. Utes moved into the area by the 1300's, but left behind no structures. By the 1700s, they were joined by Navajo and Paiute people, although their use of the park was limited.

In the 1770s, the Escalante and Dominguez parties traveled through the area. French and American trappers entered the area in the 1800s. In 1869, John Wesley Powell completed his first expedition down the Green and Colorado rivers, including the portions in what is now Canyonlands National Park.

From the 1880s until 1975, much of the region of Canyonlands was grazed. Cattle rustlers and outlaws hid in the region too, including the Robbers Roost area near the Maze which served as a refuge for outlaws including Robert Leroy Parker (Butch Cassidy).

Mining began with the uranium boom of the 1950s. This resulted in a vast network of roads being built in the previously unroaded area. This includes some now-popular, 4-wheel-drive and mountain bike routes, such as the White Rim Trail.

In the 1950s and 1960s, Arches National Monument’s superintendent, Bates Wilson, advocated for the designation of a park for the Canyonlands region. In September of 1964, President Johnson established Canyonlands National Park.

Capitol Reef National Park

Capitol Reef is a long, linear park that follows the mostly north-south trending Waterpocket Fold, a spectacular 100-mile long fold in Earth’s crust known as a monocline. Elevations range from 4,200 feet to 9,800 feet. The lowest elevations are on the east side of the park—the downdropped side of the monocline, and the highest are on the west side of the park—the uplifted side of the monocline.

The park has several distinct regions. In the northern part of the park is Cathedral Valley. Rock layers in Cathedral Valley have a gentle inclination of 3 to 5 degrees to the east and appear nearly horizontal. Deep erosion has carved Cathedral Valley's free-standing monoliths, or temples, out of the soft reddish-orange Entrada Sandstone. South of Cathedral Valley, the Fremont River bisects the park east to west. South of the river is the park's scenic drive, which travels into an area of narrow gorges, towering cliffs, and large sandstone domes. The name Capitol Reef is partially derived from these large, white domes of Navajo Sandstone: "capitol" for the white domes that resemble capitol building rotundas, and "reef" for the rocky cliffs which are a barrier to travel, like a coral reef. The long, narrow southern region of the park includes many canyons, most notably the Halls Creek Narrows.

Topographic relief created a variety of habitats, such as perennial streams, water- pockets, hanging gardens, and dry washes, which are home to a diversity of flora and fauna in the park. "Waterpockets" are basins that form in many of the sandstone layers as they are eroded by water. These basins are common throughout the fold, thus giving it the name "Waterpocket Fold."

Early human occupation of the park was by the Fremont people, from about AD 700 to AD 1300. The culture was named for the Fremont River and its valley in which many of the first Fremont sites were discovered. Several types of artifacts left by the Fremont people have been identified, including baskets, smooth and corrugated gray pottery, and moccasins made from the hides of large animals. The most unique artifacts are clay figurines of unknown significance to the Fremont people. Also, a variety of pictographs and petroglyphs are scattered throughout parts of the park.

The pioneer community of Fruita, about one mile from the visitor center, was settled in 1880 by Mormon pioneers. The National Park Service now manages the historic orchards, which contain about 2,700 trees (mostly cherry, apricot, peach, pear, and apple), as part of Rural Historic Landscape.

The park was first designated a national monument in 1937, and was later expanded and re-designated a national park in 1971.

Natural Bridges National Monument

Natural Bridges protects some of the finest examples of natural stone architecture in the southwest. The monument is located on a piñon -juniper covered mesa bisected by deep canyons. Where meandering streams cut through the canyon walls, three natural bridges formed: Kachina, Owachomo and Sipapu.

At an elevation of 6,500 feet, the park is home to a wide variety of plants [no animals listed] including piñon -juniper forests and remnant stands of Douglas fir and ponderosa pine. Fragile soil crusts also occur here.

Rock art and stone tools dating from the Archaic period, 7000 BC to AD 500, document that hunter-gatherer groups were the first known human occupants of the park. Around AD 700, ancestors of today's Pueblo people moved into the area to farm the mesa tops. These ancestral Puebloan people lived in the region until the 1300s, when they migrated to the south. Navajo and Paiute people lived in the area during later times, and Navajo oral tradition holds that their ancestors lived among the early Puebloans.

In 1883, prospector Cass Hite wandered up White Canyon from his base camp along the Colorado River in search of gold. What he found instead were three magnificent bridges that water had sculpted from stone. In 1904, National Geographic Magazine publicized the bridges, and in 1908 President Roosevelt established Natural Bridges National Monument, Utah's first National Park Service area.

Appendix F: Park Geological Settings

All four parks are located on the Colorado Plateau, a geologic province encompassing most of southern Utah and northern Arizona, northwest New Mexico, and western Colorado. The Plateau is characterized by relatively horizontal sedimentary rock layers that have been uplifted as much as 10,000 feet with relatively little deformation, with the exception of a number mostly north-south trending folds known as monoclines. Waterpocket Fold in Capitol Reef is a classic example of one of the monoclines.

For hundreds of millions of years, material was deposited in what is now southeast Utah. As movements in Earth's crust altered surface features and the North American continent migrated north from the equator, the local environment changed dramatically. Over time, southeast Utah was flooded by oceans, crisscrossed by rivers, covered by mudflats, and buried by sand. The strata records changes in climate and biota spanning from the Pennsylvanian through Tertiary periods.

Until about 15 million years ago, most of the area was near sea level. Local uplifts and volcanic activity had created features like Capitol Reef's Waterpocket Fold and the La Sal Mountains near Moab, but then movements in Earth's crust caused the whole area to rise. Today, the average elevation is over 5,000 feet above sea level.

The following is a stratigraphic column of rock units in or near the four parks:

Name of Rock Strata	Geologic Period	Millions of Years Ago
Abajo, Henrys and La Sal Mtns	Tertiary	1.6 to 65
Green River Formation		
Wasatch/Claron Formation		
Mesa Verde Group	Cretaceous	65 to 144
Mancos Shale		
Dakota Sandstone		
Cedar Mtn/Burro Canyon		
Morrison Formation	Jurassic	144 to 208
Entrada Sandstone		
Navajo Sandstone		
Kayenta Formation		
Wingate Sandstone		
Chinle Formation	Triassic	208

Moenkopi Formation		
White Rim/DeChelley Sandstone	Permian *Cutler Undivided	245 to 286
Organ Rock Formation		
Cedar Mesa Sandstone		
Lower Cutler/Halgaito Shale		
Honaker Trail Formation	Pennsylvanian	286 to 320
Paradox Formation		

Arches National Park

The two prominent rock formations visible in Arches are both Jurassic in age: the Entrada Sandstone, in which most of the arches are formed, and the Navajo Sandstone. Development of the arches has resulted from the unstable salt deposits in the underlying Pennsylvanian-age Paradox Formation. The salt deposits, under the weight of the overlying sedimentary layers, are unstable and flow. This movement caused the surface rocks to buckle, shift and crack, thrusting some sections upward into elongated domes, dropping others into surrounding cavities or valleys, and causing vertical cracks which would later contribute to the development of arches. Water seeped into cracks and joints, eroded the cement holding the sand together, and in combination with frost-wedging, formed a series of free-standing fins. Many damaged fins collapsed. Others, with the right degree of hardness and balance, have survived as the world famous features of Arches National Park.

Canyonlands National Park

Uplift of the Colorado Plateau marked a shift from a depositional environment to one of erosion. The Colorado and Green rivers began to downcut and are now entrenched in canyons over 2,000 feet deep. Layers exposed in Canyonlands range from the Pennsylvanian Paradox Formation through the Jurassic Navajo Sandstone. Particularly prominent are the Permian Cedar Mesa Formation of the Needles and Maze Districts, and the Permian White Rim Sandstone that forms a prominent bench within the Island in the Sky District.

The spires of the Needles District formed in a similar way to the arches in Arches National Park. Joints in the rock were formed in two different ways. The first was related to the Monument uplift, which begins around the Needles District and trends southwest all the way to Monument Valley. This uplift caused brittle rock, like the Cedar Mesa Sandstone, to crack as it was bent upward, forming a set of joints in a northeast-southwest direction.

The thick salt layer of the Paradox Formation is the second cause of joint formation. Underneath the Needles District the salt is flowing slowly toward the Colorado River and dragging the overlying layers with it. As the upper layers became stretched, they also fractured into joints. This action created a set of joints running northwest-southeast. In the Needles area, the two sets of joints meet and form square blocks of rock between the joints. As water and frost-wedging widened the joints, the squares were sculpted into pillars and spires that are today the Needles of Canyonlands.

The grabens in the Needles District of Canyonlands National Park are a system of linear collapsed valleys, also caused by the movement of the underlying salt. The grabens begin near the confluence of the Green and Colorado rivers and run roughly parallel to Cataract Canyon for 25 km, veering slightly west before they end. The grabens are a very young geologic feature. Graben growth is thought to be a slow process where small, seismically undetectable movement occurs: as little as one inch per year. The grabens continue to drop and slide toward the river today, and are a fascinating feature of the Needles District.

Capitol Reef National Park

Nearly 10,000 feet of sedimentary strata are found in the Capitol Reef area. These rocks range in age from the Permian White Rim Sandstone (as old as 270 million years old) to the Cretaceous Mancos Shale (as young as 80 million years old.). The Waterpocket Fold has tilted the geologic layers such that the layers on the west side of the Fold have been lifted more than 7,000 feet higher than the layers on the east. Therefore, the older rocks are found in the western part of the park, and the younger rocks are found near the east boundary.

Layer-upon-layer of sedimentary rocks records nearly 200 million years of geologic history. Rock layers in Capitol Reef reveal ancient climates as varied as rivers and swamps (Chinle Formation), Sahara-like deserts (Navajo Sandstone), and shallow ocean (Mancos Shale).

Waterpocket Fold formed between 50 and 70 million years ago when a major mountain-building event in western North America, the Laramide Orogeny, reactivated an ancient buried fault. When the fault moved, the overlying rock layers were draped above the fault and formed a monocline.

Natural Bridges National Monument

One layer of rock dominates the geology of Natural Bridges, the Permian Cedar Mesa Sandstone. Since the uplift of the Colorado Plateau, meandering streams have cut down through the sandstone and, in places, have cut through canyon walls at a meander, forming the three natural bridges for which the park was designated.

Appendix G: Compilation of Notes taken during the Scoping Session

June 5, 2002

<u>1. Desert surface crusts and fissures</u>
-This geoindicator includes biological/physical crusts and pavements

Importance to park ecosystem:
Benefits of soil crusts are increasing water infiltration, stabilizing and windproofing attributes, fixing atmospheric nitrogen for vascular plants, providing carbon to the interspaces between vegetation, secreting metals that stimulate plant growth, capturing dust (i.e. nutrients) on their rough, wet surface, and decreasing surface albedo
Human Impact:
ARCH – 75% was heavily grazed until 1974 (cow trespass still occurs) and soil nutrient cycles have not recovered
ARCH – has greater visitation than NABR, CARE, and CANY and extensive damage has occurred along trails
CANY – impacted by past grazing
CARE – was totally grazed until 1988 and a buy-out began and there are still 2 large areas currently being grazed
NABR – Less cattle impact
Significance to natural resource managers:
Concerns due to the fact that the soil has not recovered from past and current grazing and visitor use
Additional notes:
Monitoring of crusts in vegetation plots began 2002 in ARCH
Soil crust monitoring always require ground-truthing methods
Monitoring focuses on human activities
Protocols for soil crust monitoring exist
Sampling could be done by a GIP

<u>2. Dune formation and reactivation</u>

Importance to the ecosystem:
Although dunes cover a large part of the landscape, they were given a middle-ranking because they are not as active as systems like GRSA and WHSA
Dunes hold water and certain nutrients
Human Impact:
ARCH – trespassing cows in Willow Flat area trample and eat vegetation causing dune reactivation, and visitor use on dunes at the Fiery Furnace
NABR – no grazing and minimal dune coverage
CANY – grazing on orange cliffs creates windblown sand that reaches the park
CARE – current grazing is a concern
Significance to natural resource managers:
ARCH – management has shown their concern by installing fences and making interpretive efforts to inform the public to stay off the dunes in the Fiery Furnace

CARE – An astragulus species (Harrison's milkvetch) which is rare, could be impacted by dune reactivation from visitor use and current grazing (esp. at Hickman Bridge)
Additional notes:
CANY - concerns that removing the top 1 meter of sand could alter the area's water holding capability near the surface
CANY – data collected in CANY can be applied to other parks in this area
Dunes are a resource for paleoclimate information – paleosols in the dunes indicate changes in the ecosystem

11. Groundwater Quality

Importance to ecosystem:
Hanging gardens are unique features that contain rare and unique plant species
Hanging gardens provide important wildlife habitat
Health and safety issues regarding water quality for human use
Human Impact:
CANY – old landfill in NEED (located 3,000ft from visitor center well) used from 1966 to 1987; unregulated dumping occurred
CANY – unknown affects of abandoned mines and oil and gas wells (e.g. casings may deteriorate over time)
CANY – water removed during dewatering of oil well sites is supposed to be removed, although sometimes it is sprayed on roads (affects unknown)
CARE – standing water in mines is an issue (not an issue in other parks)
CARE – NPS septic field near Fremont River is not monitored
NABR – Uranium and copper mining affects are unknown
ARCH – Human impacts (e.g. grazing) may impact Courthouse Wash springs and seeps
Significance to natural resource managers
Parks are regularly monitoring springs but have not created monitoring wells due to the absence of any serious problems
Additional Notes:
GRD is a contact for oil and gas well plugging records that show locations and dates
All parks need to create PMIS statements to support research, inventory, and monitoring studies

13. Groundwater level and discharge

Importance to ecosystem:
100% of park water supply is from groundwater
"Water is life, water is everything"
Human Impact:
Limited resource and therefore potential for human impacts are great
Great unknowns about current human impacts to groundwater level and discharge
Significance to natural resource managers:
Groundwater is a limited and valuable resource that is poorly understood in the parks and the resource managers realize this
Additional notes:

Rod Parnell can be contacted for additional methods to characterize recharge areas and flow directions
Charlie Scheltz in CANY has submitted a PMIS to characterize recharge areas and flow directions

<u>3. Dust storm magnitude duration and frequency</u>
- Single events on the scale of days

Importance to ecosystem:
Plants are affected by the transport of the nutrients distributed by dust storms
Dust storms play a role in soil formation and the redistribution of sediment
Possible effects to wildlife (esp. airborne birds and insects)
Human Impacts:
Regional/Global: Overgrazing and off-road use
Significance to natural resource manages:
Air quality issues
Visibility issues (hazardous travel conditions)

<u>4. Wind erosion and deposition</u>

Importance to ecosystem:
Nutrient cycling – wind transports nutrients in and out of park system
Human Impacts
Recreation such as hiking and off-road driving
Creation of social trails
Grazing
Significance to natural resource managers:
Critical for nutrient cycling which impacts plant and crust communities
Additional notes:
See Marith Reheis paragraph
Jason Neff can be contacted for 2 research topics: investigating ecosystem consequences of movement and investigating natural range of variability to landscape configuration and characteristics

<u>4a. Ecosystem structure and function</u>
-See paragraph from Webb and Parnell

<u>16. Soil Quality</u>
- Definition of soil quality – the capacity to function ecologically

Importance to ecosystem:
Soil quality affects moisture retention, nutrient cycling, soil-food webs, and aggregate structure
Soil quality degradation results in loss of certain ecosystem functions
Soils provide biogeochemical and hydrologic support for terrestrial productivity, especially vegetation growth
Human Impacts:

Due to past and present grazing, nutrient cycles have not recovered
Significance to natural resource managers:
Concerned, but very little baseline info exists
Additional notes:
An Interpretive effort is to communicate to the public the importance of staying on trails

<u>17. Soil and sediment erosion</u>
- During this discussion this geoindicator focused on water transport erosion and deposition

Importance to ecosystem:
Loss of soil results in degradation of soil quality (see #16)
Human Impacts:
CARE – topographic gradients are high, therefore erosion along roads [used for past practices (mining) and currently used] and cow trails is potentially great
Significance to natural resource managers:
Loss of soil results in degradation to the ecosystem
Additional notes:
Limited topographically high areas outside parklands (except CARE) result in minimal overland flow entering the parks

<u>18. Sediment sequence and composition</u>

Importance to ecosystem:
Low importance because sediment sequence does not affect ecosystem health. This geoindicator is viewed as a tool and not an active process in the ecosystem
Human Impacts:
Pollutants can be added to the system
CARE – higher impacts due to grazing
Significance to natural resource managers:
This was given a moderate rating because it could potentially help managers understand what the range of natural variability should be, but may not be of urgent concern
Additional notes:
Cores of sediment sequence and composition provide a record of long-term trends (climate and land-use)
CARE – has a higher amount of erosion by water than the other parks

<u>5. Stream channel morphology</u>

Importance to ecosystem:
Impacts the structure of the riparian corridor
Effects height of water table
Effects how floods move down river (which affect erosion rate and water quality)
Human Impacts:

Potential for human impact is great: building parking lots and structures, building floodplain structures (culverts and bridges), grazing in uplands and channels, roads and trails up streambeds, introduction of exotic species, effects from flow regulation and diversion
Significance to natural resource managers:
Affects wildlife
Impacts recreational use (e.g. boating, hiking trails)
Impacts structure of riparian corridor
Affects water quality and erosion

<u>6. Stream sediment storage and load</u>
- Added erosion for clarification and to encompass the total geomorphic picture

Importance to ecosystem:
High sediment yields affect fish and riparian plants
Increased sediment loading can result in increased overbank flooding
Human Impact:
Potential for human impact is great: building parking lots and structures, building floodplain structures (culverts and bridges), grazing in uplands and channels, roads and trails up streambeds, introduction of exotic species, effects from flow regulation and diversion
Significance to natural resource managers:
Affects wildlife
Impacts recreational use (e.g. boating, hiking trails)
Impacts structure of riparian corridor
Affects water quality and erosion
Additional notes:
Concerns for potential undercutting of the natural bridges

<u>7. Streamflow</u>

Importance to ecosystem:
T&E species rely on streams
Impacts the structure of the riparian corridor
Effects height of water table
Human Impacts:
Potential for human impact is great: building parking lots and structures, building floodplain structures (culverts and bridges), grazing in uplands and channels, roads and trails up streambeds, introduction of exotic species, effects from flow regulation and diversion
Significance to natural resource managers:
Affects wildlife
Impacts recreational use (e.g. boating, hiking trails)
Impacts structure of riparian corridor
Affects water quality and erosion

8. Surface water quality
- use WRD reports and Don Weeks will provide (Katie meeting with Don, June 17th)

9. Wetlands extent, structure, and hydrology

Importance to ecosystem:
Streambank stability
Flood water attenuation
Filters for water quality
Biodiversity (habitat for amphibians, reptiles, birds, and T&E species)
High productivity areas
Water pockets provide water for wildlife and recreationists
Human Impacts:
Potential for human impact is great: building parking lots and structures, building floodplain structures (culverts and bridges), grazing in uplands and channels, roads and trails up streambeds, introduction of exotic species, effects from flow regulation and diversion
Recreation (e.g. vehicles, hikers)
Agriculture
Removal of beavers
Significance of natural resource managers:
Current laws require managers to take action on the following: National Wetlands Protection Act, Endangered Species Act, and Clean Water Act
Additional Notes:
Tom Clark will provide information for CARE studies
Dave Sharrow will draft funding summary for wetlands inventory (Bob Higgins should follow up with Dave at a later date)

20. Seismicity

Importance to ecosystems:
Can cause damaging landslides
Human Impacts:
Deep injection of water at Potash Mine possibly induces earthquakes
Significance to natural resource managers:
Although numerous earthquakes have been recorded, they are only 2 or 3 on the Richter Scale and therefore of low significance to resource managers
Additional notes:
For further information on Potash Mine contact Phil Clause at GRD

19. Slope failure (landslides)
- This also includes debris flows and rockfalls

Importance to ecosystem:
Potential to dam rivers and streams

Landslides and debris flows covering ecosystems
Significance to natural resource managers:
There are concerns for visitor protection, but the low frequency of these events and the inability to prevent the events result in a low resource management priority
Additional notes:
Can affect roads, trails, and structures

20. Surface Displacement

Notes:
CANY – growing grabens
CARE – gypsum sinkholes
ARCH and NABR – no active features

24. Paleontological resources

Notes:
Quaternary resources –
CANY – mollusks, pack rat middens
ARCH – bones, mollusks, middens
NABR – bones and middens
CARE – middens
Older resources (Katie will get from Greg)
Concerns with theft and vandalism (CARE has identified fossil theft)

appendix H: Compilation of Notes taken during the Field Trip

June 4, 2002

Stop 1: Paleo road cut outside Courthouse Wash, contact between Chinle and Wingate looking at tracks of a bipedal dinosaur (V. Santucci, NPS FOBU)

Issues: - Poaching with respect to lucrative collection
- Lack of understanding and awareness of paleo resources among park managers (YELL – had 20 fossiliferous units that they were unaware of previous to inventory)
- Lack of a good definition of fossil creates management difficulties (Def. from Ranger, Spring 2002….'evidence of life preserved in a geologic context')

Utah and Colorado have baseline inventories
150 parks have identified paleo resources
12 have paleo in enabling legislation
paleo monitoring: identify location, proximity to visitors, rank factors such as lithology, fossil density, slope, coastlines. Then plot high-risk areas on GIS layers.
Need servicewide inventory of theft and vandalism records: problem – poor documentation in the past. Solution – continue to provide rangers with enforcement training and reporting skills
Fossil resources range from Precambrian to recent

Stop 2: Arid-land fluvial systems inside Courthouse Wash (B. Webb, USGS Tucson)

Issues: - considerations of natural variability vs. human consequences are not well understood
- we don't often view geology as dynamic
- reclamation is unrealistic, so instead create "designer ecosystems" that we are comfortable with
- better recognize relationship between geomorphology and plant communities

Courthouse Wash, pre 1874, had little to no woody vegetation (mostly willows and grasses)
Since 1874, the Wash has deepened and contains more woody vegetation
Flood frequency and flood frequency change is what controls the major changes in the system (e.g. September 1896 flood)
Before the occupation of trappers, beavers would cut the woody vegetation and build check dams, that may have allowed build-up of alluvial aquifer, which supported vegetation
Need to look at big picture of understanding these systems, including: climate, ephemeral stream processes, livestock grazing
Arroyo study articles: Schumm, Stan (CSU) and another by Herford, Richard GSA Bulletin, 500 year cycles of arroyo cutting on the Colorado Plateau
Monitoring issues: difficult due to poorly understood natural relationships and the inherent dynamics of arroyo cutting. Solutions – repeat cross-sections, survey of vegetation and birds and view all as long-term monitoring
Arroyo aggradation is natural and can be due to climatic conditions and vegetation (exotic or native)

Stop 3: Atlas Mill Tailings (C. Hauke, SEUG and L. Jackson, BLM)

Issues: - Ammonia leakage

- Dust storms from the pile impacting ARCH (esp. employee housing area)
- Water movement beneath is not well understood: may impact well at ARCH, may input into Colorado River or nearby wetlands

Operation began in late 1940s and ended early-mid 1980s and was a deposit site for all surrounding mines
DOE currently owns the pile
Mitigation alternatives: capping in place or moving pile (both under consideration)

Stop 4: Human Impacts on Soil Crusts at the Windows Area of ARCH (J. Belnap, USGS CANY field station)

Issues: - how do you measure soil movement?
- impacts include trampling leading to compaction and create black brush "islands" without interspace vegetation
- comparing trampled and untrampled areas, looking at: compaction, soil input, nitrogen and other nutrients
- soil crusts are an indicator for the whole nutrient cycle and are particularly valuable indicators because they show quick response (cyanobacteria), are repeatable, and are not climate controlled

Altering visitor behavior techniques: in Australian NPS, they built "picture perfect" platforms to avoid the high numbers of visitors leaving trails to get the 'perfect picture'
Soil crust conditions can indicate human impacts (i.e. existence of mosses and lichens indicate little impact)
There can be areas that would never succeed to lichens then mosses
Indications of high use areas: no plants in the interspaces, soil deflation leading to mounding, no soil food webs, high compaction, and overall loss of soil leading to nutrient loss
Recent discover of 40,000 year-old dune deposit with paleosol is potentially a good paleoclimate record (M. Reheis, USGS Denver)

Stop 5: Impacts on Arch features at the North Window of ARCH (B. Higgins, NPS GRD)

Issues: - Is there any human impacts on the arches? Currently unknown and could be important research.
- Possible affects of acid rain and graffiti (currently not a concern in ARCH)

Stop 6: Impacts of Mineral exploration, development, and closeout at Salt Valley Overlook (L. Jackson, BLM)

Issues: - 185 mine openings in the areas that need to be closed as part of the Yellowcat Project
- Bat inventories are conducted to determine whether bat gates should be installed
- Trying to preserve soil crusts is difficult with all of these activities
- Developing management plans for reclamation is a long process (~5 years)

Political and public controversies surrounding seismic operations on BLM

Stop 7: Springs and seeps in Courthouse Wash (H. Hurlow and C. Bishop, Utah Geo Survey)

Issues: - The potential effects of nearby land development and water consumption on seeps and springs within ARCH

Recharge areas were studied and amount of area needed to recharge the springs was determined
Courthouse Wash and Sevenmile Canyon are fed by system of seeps and springs near the park boundary which issue from the base of or within the Moab member of the Curtis Formation, which is an aeolian sandstone
This is a perched groundwater system
ARCH has priority for water rights in the area, and therefore new developments cannot affect supplies to the springs

Stop 8: Impacts of Gas and Oil Exploration and Off-road Travel, at BLM Big Flat Area (L. Jackson, BLM and J. Belnap, USGS)

Issues:
- 160 miles of added thumper truck tracks
- 110 miles of ATV tracks
- 50-60 wells were drilled and only one sustained production for more than 2 years
- Oil companies have recently developed a 3D seismic project
- Bogus estimations of recovery time ranging from 1-3 years, actual time could be hundreds
- High recreation disturbance (ORV, bikes, foot traffic) to soil crusts especially resulting from people following thumper tracks

Recovery depends heavily on precipitation
Specific recovery times are approximately: cyanobacteria – 15 years, kalema – 30 years, and colored lichens – >100 years
Benefits of soil crusts are increasing water infiltration, stabilizing and windproofing attributes, fixing atmospheric nitrogen for vascular plants, providing carbon to the interspaces between vegetation, secreting metals that stimulate plant growth, capturing dust (i.e. nutrients) on their rough, wet surface, and decreasing surface albedo
SLAKE test was developed by Jeff Herrick (USDA) to measure soil stability strength
Disturbance allows for cheatgrass to invade the area
Currently we are monitoring: Nitrogen fixation, Carbon Fixation, moss and lichens, and soil stability

Stop 9: Soil Quality and Grazing Impacts at Boundary Between BLM and Deadhorse State Park (J. Belnap, USGS)

Issues: - Grazing directly impacts condition of the ecosystem as well as altering the height of the vegetation
and selective eating plants leading to decreased diversity

Unnatural or natural soil depth influences types of vegetation (e.g. grasses need at least 3 feet of depth)

Sudden change in vegetation type can be natural due to soil depth, therefore "fenceline examples" can be misleading

Stop 10: River Issues at Deadhorse Point, Colorado River Overlook (B. Webb, USGS and R. Parnell NAU)

Issues: - River flow is frequently regulated by other agencies
- Flow regulation itself disturbs natural flood peaks especially affecting drought years
- Camping results in vegetation encroachment
- Difficult to remove non-native species that have become desirable for T&E species

You should time floods when there is a pulse of sediment from the tributaries
It is important to fly aerial photography for benchmark data
1976 was the last time full aerial photography was flown in CANY
In last 40 years, Green River from Mineral Bottom to Confluence has decreased in width by 25% and was originally thought to be tamarisk, but now unsure – could be due to changes in flood peaks by climate and flow regulation
Affects of dams vary dramatically depending on settings; three main factors to consider: presence of the structure and where it is relative to sediment loads, how is water regulated – flood control and/or hydroelectric power and how this affects sediment transport, and presence/absence of non-native vegetation

Appendix I: Recommendations Table

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
Ecosystem structure-and-function characteristics as integrated indicators of geophysical (i) environments, (ii) processes, and (iii) changes/disturbances.	- process-level data are almost non-existent - of available, most information is for NEED-CANY - current availability and adequacy of soil and geologic mapping varies among parks - 10-m DEMs are available for all four parks - 1:12K aerial photos & DOQQs to be acquired within next year - veg maps scheduled to be completed within 4 years	- surficial geology maps - soil maps - vegetation maps - research will determine what to monitor, where, and with what attributes / indicators	- spatial and temporal relations among ecosystem structure / function, geologic substrates (e.g., chemistry, texture, landform attributes), and geomorphic processes - assess change-detection methods - determine which attributes are best suited as indicators
ARID AND SEMIARID			
1. Desert surface crusts (bio & physicochem) and pavements (same for all 4 parks)	- ARCH has best existing data; needs at CANY, NABR and CARE are greater	- inventory current distribution, composition and condition relative to potential	- investigate connection between ecosystem function and biocrusts - develop predictive map of potential composition / structure of crust communities in relation to environmental factors - investigate recovery rates in relation to disturbance and environmental factors - determine susceptibility to change, e.g. changing climate, UV - study population dynamics and condition

			in disturbed vs. undisturbed
2. Dune formation and reactivation	- existing data almost nonexistent - surficial geology map for small portion of NEED-CANY	- inventory required (geologic maps omit sand sheets) – i.e., map spatial distribution of sand sheets and dune features - following inventory, assess and categorize dunes / sand sheets with respect to (re)activation susceptibility - potentially monitor by repeated aerial photography (possibly with 5-year repeat interval)	- P/PE mapping to support susceptibility assessment (which will require automated climate stations) - research concerning potential (re)activation thresholds - investigate ecosystem consequences of dune reactivation
3. Dust storm magnitude, duration and frequency (bad-visibility days)	- currently being monitored at ISKY-CANY, ARCH, CARE - regional data are adequate, but local are not	- if there is a local issue....then local I&M data are required -otherwise, nothing additional is needed	- nothing locally
4. Wind erosion (ecosystem inputs / outputs of soil resources excluding water)	-some data are available from NEED-CANY for erosion & deposition - new dust traps recently installed at ARCH & ISKY-CANY (new inputs) - nothing elsewhere	- monitor movement of soil materials	- investigate better measurement / monitoring methods - investigate ecosystem consequences of movement - investigate natural range of variability in relation to landscape configuration and characteristics (Neff)
SURFACE WATER			
5. Stream channel morphology	- some cross-section data are available for Salt Creek (NEED-CANY), Courthouse Wash (ARCH), and Lost Spring (ARCH)	- conduct hydrologic condition assessments to identify actual / potential “problem reaches” for	

	- gauging stations in Courthouse Wash - miscellaneous cross-section data from Fremont R. & some other CARE systems - 1:12K aerial photos & DOQQs to be acquired within next year	prioritizing monitoring (e.g., PFC) - monitor with repeat aerial photographs - monitor with repeated cross sections	
6. Stream sediment erosion, storage and load	- no data available except for main stem of Colorado River (at Cisco) and Green River (at Green River, UT)		- conduct research concerning ungaged stream sediment storage and load - potential gaging of high-interest streams for comparative assessment of sediment measures in relation to management

7. Streamflow	- existing gages on Green R. (Green R. UT) San Rafael R. (near Green R.) Fremont R. (Cainville & above Park at Pine Crk.), Muddy River (uncertain location)...... –many other existing gages....see USGS website; - some additional flow data for CARE streams, Courthouse Wash ARCH - miscellaneous relevant data –see local USGS WRD -regionalized flood-frequency studies for UT and arid western-region states	- identify important hydrologic systems that would benefit from knowledge of streamflow - criteria: critical riparian systems, TES taxa, potential up-stream land-use effects, water-right issues, recreational use, management interest / controversy	- effects of land-use and climatic variation on stream flow - investigate paleoflood hydrology
8. Surface water quality	- see information compiled by CSU for NCPN		- investigate effects of sunscreen on water quality in springs
9. Extent, structure, and hydrology of riparian / wetland systems	- see 5,6,7,8 above - current macroinvertebrate monitoring in SEUG	- inventory location and character of wetlands (first step is to look at existing	- investigate age-structure of woody riparian plants in relation to land-use

	- current riparian bird and vegetation monitoring in SEUG - limited amphibian inventory at CANY - see veg mapping comments elsewhere	NWI maps—but these would only capture larger systems) - potentially conduct inventory of riparian & wetland condition (e.g., PFC) - inventory spatial distribution of exotics - monitor groundwater levels and surface elevations	- investigate potential linkages between amphibian parameters and wetland health

10. Lake levels and salinity			
GROUNDWATER			
11. Groundwater quality	-uncertainty exists concerning groundwater effects of old mines (all parks) and the buried landfill at NEED-CANY - baseline water quality data are available for some springs in SEUG, but not for seeps/hanging gardens	- conduct inventory (determine location) of all springs / seeps / hanging gardens (need in GIS) - assess current water quality in a prioritized subset of these, accounting for seasonal variability - (prioritized on basis of potential human use, potential human impact, ecological parameters) - inventory location and plugging record of oil/gas wells potentially connected to park groundwater systems	- use geochemical indicators to investigate groundwater flow areas, flow directions and recharge area, and groundwater age
12. Groundwater chemistry in the unsaturated zone			
13. Groundwater level and discharge	-	- install transducers and dataloggers in wells (transducers measure pressure of	- investigate / develop methods for measuring water discharge from seeps and hanging

		the water in the well) -inventory and research (concerning groundwater quality and level/discharge) must be completed prior to monitoring	gardens (Webb) - investigate additional methods to characterize groundwater recharge area and flow directions
14. Subsurface temperature regime			
15. Karst activity (salt)			

SOILS			
16. Soil quality	- some data available for NEED, ARCH; very limited elsewhere	- assess existing bio crust condition in relation to potential (as indicator of soil quality) and in relation to soil map units - repeatedly measure soil quality in previously disturbed sites to gage recovery rates in relation to environmental factors	- quantify natural range of variability in relation to environmental factors - develop predictive model for potential biological soil crust distribution/structure/function in relation to environmental factors (bio crust as indicator of soil quality) - investigate susceptibility to change, e.g. changing climate, UV - resistance and resilience to disturbance factors
17. Soil and sediment erosion & deposition by water (upland environments)	- current availability and adequacy of soil and geologic mapping varies among parks - 10-m DEMs are available for all four parks - 1:12K aerial photos & DOQQs to be acquired within next year - veg maps scheduled to be completed within 4 years - some data are available	- conduct condition assessments (e.g., qualitative hydrologic function—rangeland health) - stratify assessments in relation to landscape units and potential impacts - stratify monitoring in relation to	- investigate / develop methods for monitoring this quantitatively and affordably .... and determine where best to monitor (Webb)

	for fluvial erosion of sandy soils at NEED	landscape units and results of condition assessments	

18. Sediment sequence and composition	- some data are available from auger holes, soil pits, & micro sediment sequences from soil crusts at NEED & ARCH	- none	- identify sites, acquire cores, analyze in relation to local and regional land-use histories (potential link with Colorado Plateau CESU); objectives are to quantify natural range of variability in sediment quantity and composition and effects of land use
HAZARDS			
19. Slope failure (landslides)	- no data exist for rockfalls - data exist for debris flows in CANY along river	- use repeat ground and aerial photography to monitor debris flows in Cataract Canyon (for assessment of effects on navigation) - land slides should be reported if regularly occurring (e.g., to assess potential for damming creeks/canyons)	- continue studying spatiotemporal distribution of slope failures in relation to bedrock structure & lithology
20. Seismicity	- the data exist and are quite adequate	- consider asking USGS to install seismic monitoring devices in parks (not necessary, but possibly interesting)	
21. Surface displacement (including salt dissolution features)	- graben offsets have been monitored at CANY - previous seismic data have been collected for CANY, ARCH	- continue to monitor graben offsets	

OTHER			

23. Atmospheric deposition (N, SO4)	- defer to air-quality monitoring		
24. Paleontological resources	- paleo survey has been conducted at ARCH; very limited info avail for other parks - limited surveys for potential Quaternary resources at all parks - geologic maps exist for all parks - preliminary literature searches for all parks have been conducted	- conduct comprehensive inventories - monitoring will be required, but needs will be contingent on inventory results	- research needs will follow from inventory results
25. Climate	- CANY has 5 automated stations and 30-yr daily record - WRCC website provides long-term data for parks and surrounding stations - ARCH (~50 yr) & NABR have daily data - CARE has ~35 years of daily data - CARE has 3 years of data from automated station in the parking lot	- more automated stations needed - canvas for locations of additional / unofficial recording stations	- develop spatial model of rainfall to determine what locations would benefit from a station (to support monitoring) - develop spatial distribution of PET and climatic water balance as a function of landscape / substrate features (to support monitoring)

Appendix J: Report on Water Quality

United States Department of the Interior

NATIONAL PARK SERVICE
Water Resources Division
P.O. Box 25287
Denver, Colorado 80225

IN REPLY REFER TO:

L54(2380)
ARCH-CANY-NABR-CARE/Planning

June 21, 2002

Memorandum

To: Bob Higgins, Science and Technical Services Branch Chief, Geologic Resources Division (GRD)

From: Don Weeks, Hydrologist, Planning and Evaluation Branch, Water Resources Division (WRD)

Subject: Trip Report for Travel by Don Weeks to Moab, UT, 06/03/02 – 06/06/02.

PURPOSE: The Geologic Resources Division held a Geoindicators Workshop in Moab, Utah for Canyonlands National Park (CANY), Arches National Park (ARCH), Natural Bridges National Monument (NABR), and Capitol Reef National Park (CARE). The purpose of the workshop was to generate recommendations for long-term monitoring of *geoindicators* in conjunction with Park Vital Signs Monitoring.

ITINERARY: I drove from Lakewood, CO to Moab, UT on 06/03/02. The workshop began at 2 p.m. and continued until 6 p.m. that evening. On 06/04/02, I participated in the full day field trip to Arches National Park and Canyonlands National Park. On 06/05/02, I participated in the Geoindicators scoping session, ranking various *geoindicators* based on importance to the park. On 06/06/02 I drove back to Lakewood, CO.

CONTACTS:
Jayne Belnap, U.S. Geological Survey, Moab, UT
Charles Bishop, Utah Geological Survey, Salt Lake City, UT
Tom Clark, Capitol Reef National Park, Torrey, UT
Larry Coats, Northern Arizona University, Flagstaff, AZ
Craig Hauke, NPS, Southeast Utah Group, Moab, UT
Bob Higgins, NPS, Geologic Resources Division, Lakewood, CO
Hugh Hurlow, Utah Geological Survey, Salt Lake City, CO
Lynn Jackson, Bureau of Land Management, Moab, UT
Katie KellerLynn, NPS Contractor, Estes Park, CO
Alison Koch, Fossil Butte National Monument, Kemmerer, WY
Dan Martin, Brigham Young University
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Mark Miller, NPS, Northern Colorado Plateau Network, Moab, UT
Mary Moran, NPS, Southeast Utah Group, Moab, UT
Tom Morris, Brigham Young University
Jason Neff, U.S. Geological Survey, Denver, CO
Rod Parnell, Northern Arizona University, Flagstaff, AZ
Andy Pearce, Aztec Ruins National Monument, Aztec, NM

Doug Powell, Bureau of Land Management, Kanab, UT
Marith Reheis, U.S. Geological Survey, Denver, CO
Richard Reynolds, U.S. Geological Survey, Denver, CO
Bruce Rodgers, NPS, Southeast Utah Group, Moab, UT
Vince Santucci, Fossil Butte National Monument, Kemmerer, WY
Charlie Schelz, NPS, Southeast Utah Group, Moab, UT
Dave Sharrow, Zion National Park, Kanab, UT
Gery Wakefield, NPS, Southeast Utah Group, Moab, UT
Robert Webb, U.S. Geological Survey, Tucson, AZ
Mike Young, Westfield State College, Westfield, MA

DISCUSSION:

I participated in the three-day workshop in Moab, UT to assist with addressing significant geophysical processes that affect ecosystem health and evaluate human stressors impacting those processes for Canyonlands National Park (CANY), Arches National Park (ARCH), Natural Bridges National Monument (NABR), and Capitol Reef National Park (CARE). Recommendations for long-term monitoring of *geoindicators* in conjunction with Park Vital Signs Monitoring were also discussed.

The first day (June 3) was designed as a general overview session. Background information was presented for the four NPS units: CANY, ARCH, NABR, and CARE. An overview of the Inventory and Monitoring Program was also provided. The second day (June 4) was a full-day field trip that included eight stops at Arches NP, Canyonlands NP, and the Atlas tailing landfill. Discussions included 1) impacts to paleontological resources, 2) dynamics and impacts to fluvial systems, 3) impacts associated with mineral development, and 4) impacts to biological soil crusts. The third and final day (June 5) was an all-day scoping session to rank the numerous geoindicators for CANY, ARCH, NABR, and CARE to establish a priority to park-specific importance. Existing baseline data for each of these geoindicators was listed, including inventory and monitoring needs and research needs.

ACTION ITEMS:

1. Don Weeks will identify potential sources for groundwater quality impacts at CANY, ARCH, NABR, and CARE from existing reference materials (see Attachment 1).
2. Don Weeks will provide references to existing water quality baseline data for CANY, ARCH, NABR, and CARE (see Attachment 2).

cc: GRD Contractor: KellerLynn
2380: Flora, Vana-Miller, Kimball, Pettee, Jackson

Attachment 1

Potential Sources for Groundwater Quality Impacts

Canyonlands National Park

Approximately 1 miles south of the CANY Visitor Center (Needles District) is an abandoned landfill that operated from 1966 to 1987. Hazardous substances including paint thinners, pesticides, human wastes, and oils were disposed at this landfill during operation. The soils consist of alluvial and eolian deposits (loose sandy material) of high permeability 10 to 20 feet deep; thus the potential for groundwater contamination exists in the area. The closest domestic well is 3000 feet north of the landfill (Cudlip et al., 1999). A report by Mesa State College (1996) concluded that release of hazardous substances to the groundwater associated with Salt Creek, Lost and Squaw canyons may have occurred. A total of eight National Park drinking wells are located in this area, with four designated for capping.

Herbicides to decrease the number of tamarisk stands may cause water quality problems associated with streams and springs in CANY.

Trespass cattle at a number of springs in Canyonlands also raises a concern regarding maintenance of good water quality (Cudlip et al., 1999). Impacts include trampled soil and vegetation, increased sedimentation, and elevated levels of fecal contamination (Berghoff and Vana-Miller, 1997).

Groundwater quality in CANY can be poor due to natural causes. For example, the Island in the Sky District encompasses parts of the White Rim formation. The limited groundwater resources here have high total dissolved solids, exceeding 1990 mg/L (Huntoon, 1977).

Water rights associated with springs and groundwater wells are a concern for CANY. Should boundaries of CANY ever be extended, water rights questions would arise for water sources within the additions.

Several abandoned oil and gas wells exist within and close to NPS boundaries. Fossil fuels are generally associated with marine shales and extraction of these resources results in increased dissolution of soluble minerals. Development of test wells can result in the discharge of saline groundwater. Old well casings my corrode resulting in a release of saline waters into the well. Abandoned wells should be properly plugged to minimize any potential for cross-contamination of freshwater aquifers.

Abandoned mines are a water quality concern for groundwater resources. No active mines are on NPS lands in the Colorado Plateau, but numerous abandoned radium and uranium sites in or immediately adjacent to NPS units exist.

Umetco Minerals Corporation has supervised the reclamation of the Uravan Mill Site since 1988 when the mill was decommissioned. Located approximately 50 river miles away from the Colorado River near Moab, uranium ore has been mined at this site since the early 1900s. Radiological contamination of groundwater, soils, and facilities caused the U.S. EPA to consider designating Uravan a Superfund site regulated under CERCLA and RCRA.

1995 Summo USA Corporation submitted a Plan of Operation for copper mining in Lisbon Valley near Canyonlands. Operations would include crushing the ore, piling and sprinkling with sulfuric acid…dissolving the copper…the solution would be pumped out and the copper recovered. Mining and processing would occur for a 10-year period, with reclamation taking an additional 5 years. Groundwater appears to move northeast toward the Dolores River and a fault system appears to block movement of groundwater to the east toward the Needles District (Cudlip et al., 1999).

The Texas Gulf Potash Mine located on the Colorado River at the town of Potash. The evaporite consists of potash (KCl) as well as large amounts of salt (NaCl). The salt was stockpiled, and its proximity to the

Colorado River raised concern that leachates could impact the local water resources. There are several leases in the area, including some prospecting applications that have not been processed. If an entity were interested in mining the area, the Bureau of Land Management would guide the development of an Environmental Impact Statement (Cudlip et al., 1999).

According to Long and Smith (1996), potential impacts to park springs from recreation and visitor use has not been adequately quantified in the past. Table 1 lists spring sites that exceeded use designation standards in Canyonlands National Park.

Table 1. Spring sites in Canyonlands National Park that exceeded use designation standard, 1983-1993 (Long and Smith, 1996).

Station ID (spring type)	Parameter	Total Samples	Exceed Standard[1]
2.4 Mile Loop Pool: BS2 (Wall Spring)	dissolved oxygen	11	6
	pH	13	2
	dissolved phosphorus (as P)	4	1
Soda Spring: BS3 (Unknown)	total copper	3	2
	total coliform	2	1
Big Spring (upper): BS4 (wash spring)	dissolved oxygen	12	5
	pH	14	4
	total copper	13	2
Big Spring (lower): BS6 (Plunge Seep)	dissolved oxygen	13	3
	pH	15	3
	total phosphorus (as P)	4	2
	total copper	13	1
	total iron	13	1
	turbidity	4	1

Station ID (spring type)	**Parameter**	**Total Samples**	**Exceed Standard[1]**
Davis Canyon: DC8 (wash spring)	dissolved oxygen	12	9
	pH	13	6
	total copper	12	3
	fecal coliform	5	1
	turbidity	4	2
Junction Spring: HC1 (wash spring)	total copper	13	3
Holeman Spring: HSB1 (alcove spring)	dissolved oxygen	13	1
	pH	13	1
Horseshoe (upper): HSC1(wash spring)	dissolved oxygen	10	2
	pH	10	3
	dissolved phosphorus (as P)	4	1
	total copper	13	2
Horseshoe (lower): HSC2 (wash spring)	dissolved oxygen	7	3
	pH	7	1
	total copper	8	1
	total iron	7	3
	turbidity	2	1
Indian Creek: IC15 (intermittent stream)	total copper	1	1
	total iron	1	1
Lost Canyon: LO2 (perennial stream)	dissolved oxygen	14	4
	pH	16	6
	total copper	14	3
	total iron	13	1
Little Spring Canyon: LS1 (wash spring)	dissolved oxygen	13	3
	pH	14	4
	total phosphorus (as P)	4	1
	total copper	11	6
	fecal coliform	6	1
Salt Creek Lower Jump: SC21 (intermittent stream)	dissolved oxygen	12	3
	pH	15	2
	total copper	14	2
	total iron	13	1
	fecal coliform	7	1
	turbidity	4	1
Shafer Spring: SHS1 (wash spring)	dissolved oxygen	10	3
	pH	10	1
	total phosphorus (as P)	1	1
	total copper	10	3
	turbidity	1	1

Station ID (spring type)	**Parameter**	**Total Samples**	**Exceed Standard[1]**
Plug Spring: SF1 (wash spring)	dissolved oxygen	12	3
	pH	14	4
	total copper	15	3
	total iron	15	4
Harvest Scene: SF2 (wash spring)	dissolved oxygen	14	7
	pH	15	4
	total copper	15	2
	total iron	15	1
	turbidity	4	3
Maze Overlook: SF3 (wash spring)	dissolved oxygen	15	1
	pH	16	2
	total copper	15	1
Chocolate Drops: SF4 (wash spring)	dissolved oxygen	14	6
	pH	15	3
	total copper	13	1
Gap Downstream: SF5 (wash spring)	dissolved oxygen	14	6
	pH	14	3
	total copper	14	2
Gap Upper Spring: SF6 (wash spring)	dissolved oxygen	10	4
	total copper	12	4
Lower South Fork: SF7 (wash spring)	dissolved oxygen	9	7
	pH	9	3
	total copper	10	2
Squaw Canyon Upper: SQ1A (intermittent stream)	dissolved oxygen	8	2
	total copper	8	2
Squaw Canyon Lower: SQ2 (intermittent stream)	dissolved oxygen	13	4
	pH	15	4
	total phosphorus (as P)	3	1
	total copper	13	1
	total iron	12	1
	fecal coliform	8	1
	turbidity	3	2
Cave Spring: SQ3 (alcove seep)	dissolved oxygen	14	4
	pH	17	5
	total phosphorus (as P)	4	3
	total copper	14	1
	total iron	14	1
	turbidity	4	3

Station ID (spring type)	**Parameter**	**Total Samples**	**Exceed Standard[1]**
The Neck Spring:TC1 (alcove seep)	dissolved oxygen	9	2
	pH	9	3
	total copper	10	1
Cabin Spring: TC2 (alcove spring)	dissolved oxygen	17	2
	pH	17	4
	total copper	15	1
	fecal coliform	9	1
Taylor Canyon Spigot: TC3 (spigot (drilled))	dissolved oxygen	1	1
	total copper	1	1
Ernie's Country West: WA1 (alcove seep)	dissolved oxygen	15	1
	total copper	15	2
Ernie's Country East: WA2 (alcove seep)	pH	16	2
	total copper	15	2
Water Canyon:WC1 (wash spring)	dissolved oxygen	4	1
	total copper	3	1
Lathrop Canyon: WR1 (wash spring)	dissolved oxygen	12	4
	pH	12	1
	total copper	11	7

1 The standard value used is the most stringent standard of the use designations listed for each parameter.

Arches National Park

Contaminated groundwater impacts from the Atlas tailing pile. In 1996, alpha level sampling from groundwater monitoring wells around the site revealed alpha concentrations of 9.2 pCi/L (February), 6.0 pCi/L (March), and 24 pCi/L (July). The state standard is 15 pCi/L. Elevated ammonia levels detected downstream from the tailing pile on the Colorado River may influence groundwater chemistry in the immediate area. The potential for movement of contaminated groundwater under the mill and tailing site is possible due to hydraulic pressure caused by hydraulic head which exists above the base of the tailings pile (Cudlip, et al., 1999). The Moab Fault, located between the tailings pile and ARCH Visitor Center, is thought to provide some level of protection to the drinking water well at the Visitor Center.

Several abandoned oil and gas wells exist within and close to NPS boundaries. Fossil fuels are generally associated with marine shales and extraction of these resources results in increased dissolution of soluble minerals. Development of test wells can result in the discharge of saline groundwater. Old well casings my corrode resulting in a release of saline waters into the well. Abandoned wells should be properly plugged to minimize any potential for cross-contamination of freshwater aquifers.

Water rights associated with springs and groundwater wells are a concern for ARCH. Two situations exist where water rights on springs are questionable. They include a spring located in Lost Spring Canyon northeast of ARCH and one located in Courthouse Wash in ARCH. The spring in Lost Spring Canyon is adjacent to a parcel, which Congress added to ARCH in 1998. The Courthouse Wash spring is just inside the park boundary and has been used to water livestock. Concerns include the impacts to these springs from cattle grazing, and the need for water to support park

purposes such as recreational use and resource preservation. Should boundaries of ARCH ever be extended, water rights questions would also arise for water sources within the additions (Cudlip, et al., 1999).

Trespass cattle at springs in Arches also raises a concern regarding maintenance of good water quality. Impacts include trampled soil and vegetation, increased sedimentation, and elevated levels of fecal contamination (Berghoff and Vana-Miller, 1997).

According to Long and Smith (1996), potential impacts to park springs from recreation and visitor use has not been adequately quantified in the past. Table 2 lists spring sites that exceeded use designation standards in Arches National Park.

Table 2. Spring sites in Arches National Park that exceeded use designation standards, 1983-1993 (Long and Smith, 1996).

Station ID (spring type)	**Parameter**	**Total Samples**	**Exceed Standard[1]**
Courthouse Wash: CW1 (perennial stream)	pH	17	2
	total phosphorus (as P)	6	2
	total copper	14	1
	fecal coliform	8	3
	turbidity	6	3
Freshwater Canyon: FW1 (wash spring)	dissolved oxygen	17	2
	pH	18	3
	total copper	14	2
Sleepy Hollow: SH1 (alcove spring)	dissolved oxygen	16	2
	turbidity	6	1
Seven Mile Canyon: SM1 (wash spring)	dissolved oxygen	11	5
	pH	10	4
	total copper	10	7
Salt Valley Wash: SVW1 (wash spring)	dissolved oxygen	4	2
	pH	4	1
	total phosphorus (as P)	2	2
	total copper	4	4
	total iron	4	3
	total lead	2	1
	total zinc	2	1
	turbidity	2	2

Station ID (spring type)	**Parameter**	**Total Samples**	**Exceed Standard[1]**
Salt Wash: SW3 (perennial stream)	dissolved oxygen	17	1
	pH	18	3
	total copper	15	2
	total silver	4	1
	turbidity	4	2
Salt Spring: SW5 (wall spring)	pH	11	2
	total copper	9	1
Willow Spring: WS1 (wash spring)	dissolved oxygen	13	2
	pH	13	2
	total copper	15	5
	total coliform	12	1
	fecal coliform	9	1

1 The standard value used is the most stringent standard of the use designations listed for each parameter.

Natural Bridges National Monument

Threats to water resources include uncontrolled camping, ORVs, abandoned mines, herbicides used in tamarisk control, oil and gas development, trespass cattle. Threats inside the park are mainly from recreational overuse. Agriculture and mining (uranium and copper) outside NABR may impact groundwater resources. Springs and seeps appear to be of good quality but there is some evidence that aluminum, chloride, manganese and zinc may be a problem in some areas.

Oil and gas exploration and development in this area could become a future source of contamination to water resources. While lands in NABR are withdrawn from mineral leasing, oil and gas leases exist on BLM lands 2 to 3 miles from NABR's boundary. Though none of these leases are currently in production, there is an increasing potential for oil and gas development within White Canyon. Fossil fuels are generally associated with marine shales and extraction of these resources results in increased dissolution of soluble minerals. Development of test wells can result in the discharge of saline groundwater. Old well casings my corrode resulting in a release of saline waters into the well. Abandoned wells should be properly plugged to minimize any potential for cross-contamination of freshwater aquifers.

Abandoned uranium and copper mines adjacent to NABR are a concern for groundwater resources in the area. Runoff from abandoned mine areas may represent water quality threats.

Trespass cattle are a constant problem at NABR. Potential impacts to water resources include trampled soil and vegetation increasing sedimentation, and elevated levels of fecal contamination (Berghoff and Vana-Miller, 1997).

Herbicides to decrease the number of tamarisk stands may cause water quality problems associated with streams and springs in NABR.

According to Long and Smith (1996), potential impacts to park springs from recreation and visitor use has not been adequately quantified in the past. Table 3 lists spring sites that exceeded use designation standards in Natural Bridges National Monument.

Table 3. Spring sites in Natural Bridges National Monument that exceeded use designation standards, 1983-1993 (Long and Smith, 1996).

Station ID	Parameter	Total Samples	Exceed Standard[1]
Kachina Bridge Pool: KB1 (plunge seep)	dissolved oxygen	14	3
	pH	15	5
	total iron	11	1
	turbidity	5	1
Owachomo Bridge: OB1 (plunge pool)	dissolved oxygen	12	1
	pH	13	2
	total copper	12	1
	total iron	12	1
	turbidity	3	2
Sipapu Bridge: SB1 (intermittent stream)	dissolved oxygen	12	4
	pH	14	2
	turbidity	5	1
Horsecollar Seep:SB2 (alcove seep)	dissolved oxygen	6	1
	pH	6	2
	total copper	6	2
To-ko-chi Canyon (wash spring)	dissolved oxygen	9	2
	pH	9	4
	total copper	7	3
	total iron	8	2
	turbidity	3	1

[1] The standard value used is the most stringent standard of the use designations listed for each parameter.

Capitol Reef National Park

Abandoned uranium mines are a concern for groundwater resources. No active mines are on NPS lands in the Colorado Plateau, but abandoned uranium sites in or immediately adjacent to CARE exist. Runoff from abandoned mine areas may represent water quality threats. Natural radioactivity may occur in portions of the Fremont River as it flows through the uranium-ore bearing strata of the Chinle formation.

Oil and gas exploration and development in this area could become a future source of contamination to water resources. CARE currently has one lease for oil and gas drilling. Fossil fuels are generally associated with marine shales and extraction of these resources results in increased dissolution of soluble minerals. Development of test wells can result in the discharge of saline groundwater. Old well casings my corrode resulting in a release of saline waters into the well. Abandoned wells should be properly plugged to minimize any potential for cross-contamination of freshwater aquifers. Oil exploration began in the early 1900s with limited success. With increases in drilling and exploration technology, minerals development in the area could be renewed (Northern Colorado Plateau, 2002).

Trespass cattle at springs in CARE also raises a concern regarding maintenance of good water quality. Impacts include trampled soil and vegetation, increased sedimentation, and elevated levels of fecal contamination. A total of 1,380 Animal Unit Months of winter cattle grazing is permitted on 87,000 acres in the northern and central portions of the park (Northern Colorado Plateau, 2002).

Pesticides used by the NPS to maintain the historic orchards at CARE may pose an impact to water resources.

There were two water quality sampling stations at Ackland Spring (Ackland Spring and Ackland Seep) in Capitol Reef National Park that were sampled from 1988-1992. Specific conductance, pH, ammonia, nitrate, and sulfate exceeded the screening criteria at both stations (Northern Colorado Plateau, 2002).

The last sampling recorded on Middle Desert Wash occurred in 1979. Most exceedances occurred at spring and seep stations. Chloride, sulfate, mercury, and aluminum exceeded the screening criteria at least once (Northern Colorado Plateau, 2002).

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Attachment 2

Baseline Information for Surface Water Quality

Canyonlands National Park

Current Water Quality Monitoring (table modified from Sam Kunkle 2002 {kunkle@earthlink. Net}, Northern Colorado Plateau Park Water Quality Monitoring: Thumbnail Sketches).

MONITORING STAFF in place: ~ 1/5 Prof FTE ~ 1/3 BioTech FTE (shared with SEUG)

Canyonlands NP (SEUG)	FIELD WORK	LABORATORY ANALYSES			
		PARK LAB	LOCAL LEVEL LAB	STATE LEVEL LAB	RESEARCH LEVEL LAB
FIELD METERS (Hydrolab, etc)	pH, DO, SpC				
DISCHARGE					
BACTERIA		FCs			
MACRO INVERTEBRATES				++++	
NUTRIENTS				see notes below this table	
CATIONS ANIONS					
METALS					
LOW DETECTION					
ORGANICS					
OTHER					

SAMPLING SCHEDULE: [shaded] ~ MONTHLY; ++++ ~ EVERY 6-12 MO.; xxxxx SHORT STUDIES; ///// (SEE NOTES)

Nine long-term monitoring sites at CANY. DEQ analyzes for sediment, ammonia, Ba, Ca, Cu, Pb, Mn, Se, Na, bicarbonate, carbonate, OH, total P, hardness, SpC, Al, Hg, TKN, As, Cd, Cr, Fe, Mg, K, Ag, Zn, CO_2, Cl, sulfate, alkalinity, turbidity, TDS, nitrate+nitrite, and CO_3 solids.

Baseline Water Quality Information

Connor and Kepner (1983) presents information on fish, invertebrate and water quality and quantity at Arches National Park.

Ecosystems Research Institute (1984) provided a review of water quality in the Needles District of Canyonlands and adjacent BLM lands. This included an inventory of surface and groundwater resources that may be directly or indirectly affected by the construction and operation of a high level nuclear waste facility adjacent to CANY. Includes baseline data on surface an groundwater quality; a long-term water quality monitoring program with emphasis on Lavender, Davis, Indian, and Salt Creek drainages in the park.

Long and Smith (1996) analyzed ten years (1983-1992) of data collected at 31 spring and seep sites in or near the park. Long and Smith (1996) provided a data analysis of water quality for seeps, springs, and streams.

Berghoff and Vana-Miller (1997) provided and overview of park's water resources with summary of water resource issues.

Cudlip, et al., (1999) provides an overview of the park's water resources, identifies and discusses 11 water-related issues, and includes 13 project statements that begin to address these issues.

U.S. Geological Survey (2000) summarizes the data from discharge stations, wells, streams, and lakes with both flow and water quality information for the Green River, Colorado River, and other water bodies relevant to National Parks in the state.

Schelz, C. (2001) covers the work to monitor the extensive impact on Salt Creek by a four-wheeling road, and describes and interprets the water quality impacts of the road.

Northern Colorado Plateau (2002) is currently one of several draft reports being developed for all Northern Colorado Plateau NPS units as part of the Water Quality Vital Signs monitoring effort. Each park-specific report provides a description of park water resources, identifies and discusses water-related issues, summarizes current and past monitoring, and includes a comprehensive list of references related to the park's water resources.

In 2002, the National Park Service's Water Resources Division is scheduled to complete a comprehensive summary of existing surface water quality data for Canyonlands National Park.

References

Berghoff, K. and D. Vana-Miller. 1997. Canyonlands National Park, Arches National Park, and Natural Bridges National Monument, Water Resources Scoping Report. Technical Report NPS/NRWRD/NRTR-97/94. Ft. Collins, CO. 37 pp.

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U.S. Geological Survey. 2000. Water resources data, Utah, water year 2000. Water-Data Report UT-00-1. Salt Lake City, UT. 380 pp.

Arches National Park

Current Water Quality Monitoring (table modified from Sam Kunkle 2002 {kunkle@earthlink. Net}, Northern Colorado Plateau Park Water Quality Monitoring: Thumbnail Sketches).

MONITORING STAFF in place (for SEUG): ~ 1/5 Prof FTE ~ 1/3 BioTech FTE (shared SEUG)

Arches NP (SEUG)	FIELD WORK	LABORATORY ANALYSES			
		PARK LAB	LOCAL LEVEL LAB	STATE LEVEL LAB	RESEARCH LEVEL LAB
FIELD METERS (Hydrolab, etc)	pH, DO, SpC				
DISCHARGE					
BACTERIA		FCs			
MACRO INVERTEBRATES				++++	
NUTRIENTS				see notes below this table	
CATIONS ANIONS					
METALS					
LOW DETECTION					
ORGANICS					
OTHER					

SAMPLING SCHEDULE: [shaded] ~ MONTHLY; ++++ ~ EVERY 6-12 MO.; xxxxx SHORT STUDIES; ///// (SEE NOTES)

Six long-term monitoring sites at ARCH . DEQ analyzes for sediment, ammonia, Ba, Ca, Cu, Pb, Mn, Se, Na, bicarbonate, carbonate, OH, total P, hardness, SpC, Al, Hg, TKN, As, Cd, Cr, Fe, Mg, K, Ag, Zn, CO_2, Cl, sulfate, alkalinity, turbidity, TDS, nitrate+nitrite, and CO_3 solids.

Baseline Water Quality Information

Douglas and Holden (1979) identifies species of fish, algae, and invertebrates, plus water chemistry data found at four sampling stations on Salt Wash in Arches National Park.

Connor and Kepner (1983) presents information on fish, invertebrate and water quality and quantity at Arches National Park.

Nathan (1988) describes a survey of fish, algae, aquatic invertebrates, and basic water chemistry of Salt Wash and Fresh Water Canyon in Arches National Park and compares data with 1979 study.

Long and Smith (1996) analyzed ten years (1983-1992) of data collected at 11 spring and seep sites in or near Arches National Park. Long and Smith (1996) provided a data analysis of water quality for seeps, springs, and streams.

Berghoff and Vana-Miller (1997) provided and overview of park's water resources with summary of water resource issues.

Cudlip, et al., (1999) provides an overview of the park's water resources, identifies and discusses 11 water-related issues, and includes 13 project statements that begin to address these issues.

Northern Colorado Plateau (2002) is currently one of several draft reports being developed for all Northern Colorado Plateau NPS units as part of the Water Quality Vital Signs monitoring effort. Each park-specific report provides a description of park water resources, identifies and discusses water-related issues, summarizes current and past monitoring, and includes a comprehensive list of references related to the park's water resources.

In 2002, the National Park Service Water Resources Division is scheduled to complete a comprehensive summary of existing surface water quality data for Arches National Park.

References

Berghoff, K. and D. Vana-Miller. 1997. Canyonlands National Park, Arches National Park, and Natural Bridges National Monument, Water Resources Scoping Report. Technical Report NPS/NRWRD/NRTR-97/94. Ft. Collins, CO. 37 pp.

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Capitol Reef National Park

Current Water Quality Monitoring (table modified from Sam Kunkle 2002 {kunkle@earthlink. Net}, Northern Colorado Plateau Park Water Quality Monitoring: Thumbnail Sketches).

MONITORING STAFF available at this point: 1/8 Prof FTE 1/8 Tech FTE (see Notes)

Capitol Reef NP	FIELD WORK	L A B O R A T O R Y A N A L Y S E S			
		PARK LAB	LOCAL LEVEL LAB	STATE LEVEL LAB	RESEARCH LEVEL LAB
FIELD METERS (Hydrolab, etc)					
DISCHARGE					
BACTERIA					
MACRO INVERTEBRATES		*[note: water monitoring planning underway at this time, but no monitoring at the moment]* *			
NUTRIENTS					
CATIONS ANIONS					
METALS					
LOW DETECTION					
ORGANICS					
OTHER					

*In the past CARE had specialists on staff focused on water resources nearly full time, who conducted significant WQ monitoring (note comments under references below). At this time, planning is underway for return to WQ monitoring, not yet begun.

Baseline Water Quality Information

Woodbury and Musser (1963) provided a study on physical characteristics of the Fremont River in Capitol Reef National Monument. Fish and amphibians were collected and water samples were analyzed.

Winget (1975) reports on aquatic surveys conducted at sites on the Fremont, Muddy, and Dirty Devil rivers plus the Caine Springs in Salt Wash. Measurements included stream profile, discharge, water and air temperature, specific conductance, salinity, pH, and dissolved oxygen. Samples were also taken of periphyton, zooplankton, phytoplankton, macrophytes, macroinvertebrates, and fisheries.

Utah Department of Natural Resources (1980?) survey the chemical and biological traits of Pleasant Creek and Carcass Creek in Wayne County and Bullfrog Creek and Sandy Creek in Garfield County.

Envirosphere Company (1981) includes proposals for monitoring programs at Dinosaur National Monument and Capitol Reef National Park developed on the basis of information gathered in an intensive short-term evaluation of the water resources. The primary purpose is the design of a water quality monitoring program to assure protection of the water resources and to satisfy requirements to Section 208 of the Federal Water Pollution Control Act.

Christiana and Rasmussen (1989) provides an overview of water resources in the park, describing basic hydrology, water supply, dam impact concerns, water rights, and impacts from grazing, floods, exotic vegetation, and recreation.

National Park Service (1990) provides water quality data of the Fremont River from Bricknell Bottoms through Capitol Reef National Park, 1988-89. Temperature, turbidity, conductivity, and fecal coliform bacteria were monitored.

Christiana and Rasmussen (1991) examines the hydrology and water resources of Capitol Reef National Park, the chemical quality of water resources, and the park's water uses and water budget.

Berghoff (1994) examines water quality for Capitol Reef National Park. Samples were taken at five different sites and analyzed at the Utah water quality lab.

In 1994, the National Park Service completed a comprehensive summary of existing surface water quality data for Capitol Reef National Park (National Park Service, 1994).

Lafrancois (1994) examines the biological and chemical systems of rock pools within Capitol Reef National Park.

Brammer (1997) surveyed benthic insects along Pleasant Creek and the collections used to calculate stream indices for water quality.

Millennium Science and Engineering (2001) provides a water quality review of the Fremont River.

Northern Colorado Plateau (2002) is currently one of several draft reports being developed for all Northern Colorado Plateau NPS units as part of the Water Quality Vital Signs monitoring effort. Each park-specific report provides a description of park water resources, identifies and discusses water-related issues, summarizes current and past monitoring, and includes a comprehensive list of references related to the park's water resources.

The Fremont River is currently a 303(d) listed stream (impair water). As a result the Utah Department of Environmental Quality monitors the Fremont's water quality and has recently developed Total Maximum Daily Loads (TMDLs) for the river (Denton, pers. comm. 2002).

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Natural Bridges National Monument

Current Water Quality Monitoring (table modified from Sam Kunkle 2002 {kunkle@earthlink .net}, Northern Colorado Plateau Park Water Quality Monitoring: Thumbnail Sketches).

MONITORING STAFF in place: ~ 1/5 Prof FTE ~ 1/3 BioTech FTE (shared with SEUG)

NABR NM (part of SEUG)	FIELD WORK	L A B O R A T O R Y A N A L Y S E S			
		PARK LAB	LOCAL LEVEL LAB	STATE LEVEL LAB	RESEARCH LEVEL LAB
FIELD METERS (Hydrolab, etc)	pH, DO, SpC				
DISCHARGE					
BACTERIA		FCs			
MACRO INVERTEBRATES				++++	
NUTRIENTS				see notes below this table	
CATIONS ANIONS					
METALS					
LOW DETECTION					
ORGANICS					
OTHER					

SAMPLING SCHEDULE

[shaded]	++++	xxxxx	/////
~ MONTHLY	~ EVERY 6-12 MO.	SHORT STUDIES	(SEE NOTES)

Three long-term monitoring sites are NABR. DEQ analyzes for sediment, ammonia, Ba, Ca, Cu, Pb, Mn, Se, Na, bicarbonate, carbonate, OH, total P, hardness, SpC, Al, Hg, TKN, As, Cd, Cr, Fe, Mg, K, Ag, Zn, CO_2,, Cl, sulfate, alkalinity, turbidity, TDS, nitrate+nitrite, and CO_3 solids.

Baseline Water Quality Information

Long and Smith (1996) analyzed ten years (1983-1992) of data collected at 5 spring and seep sites in or near Natural Bridges National Monument. Long and Smith (1996) provided a data analysis of water quality for seeps, springs, and streams.

Berghoff and Vana-Miller (1997) provided and overview of park's water resources with summary of water resource issues.

In 2001, the National Park Service completed a comprehensive summary of existing surface water quality data for Natural Bridges National Monument (National Park Service, 2001).

Northern Colorado Plateau (2002) is currently one of several draft reports being developed for all Northern Colorado Plateau NPS units as part of the Water Quality Vital Signs monitoring effort. Each park-specific report provides a description of park water resources, identifies and discusses water-related issues, summarizes current and past monitoring, and includes a comprehensive list of references related to the park's water resources.

References

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Appendix K: Discussion on Hanging Gardens

Discussion on hanging gardens was limited during the scoping meeting. However, the importance of hanging gardens was discussed in reference to the unique and valuable habitat they provide for flora and fauna.

The following information about hanging gardens, and thoughts on potential research and monitoring of them, was written by Bob Higgins. This information is included to promote discussion regarding this unique ecosystem.

The following are Bob Higgins' thoughts:

The hanging garden ecosystems seem important and unique to the Colorado Plateau. They touch on a number of categories: 1) geoindicators (wetlands, groundwater level) and 2) inventory, monitoring and research.

I've always been impressed with the hanging gardens in the Colorado Plateau. They are such a unique ecosystem, that I feel that we, in the NPS, should place more emphasis on them. Perhaps there are a number of ways to do this.

What I am thinking about is a resource management project that includes inventory and monitoring aspects and focuses on the hanging gardens ecosystems of the NPS units within the Colorado Plateau. It could highlight integrated science approaches -- in this case biology, hydrology, geology and maybe micro-climatology to demonstrate how they all play a role in ecosystem management (natural resource management). I am especially interested in exploring how understanding geologic resources will help provide answers for the biologists. I believe that at a minimum we can design this project to bring together inventory, monitoring, geologic mapping, topographic mapping, hydrology, groundwater, biologic communities and endangered species coupled with GIS applications.

As I understand it, hanging gardens are found where there are seeps, at the contacts between sedimentary formations (sandstone-shale, sandstone-limestone) on the rock walls of the canyons on the Colorado Plateau. There is sedimentary control on the groundwater. Fractures are also important in how the water is transported from the recharge areas to the impermeable sedimentary layer. There appears to be a topographic relationship, because many of the hanging gardens are located in alcoves in the canyon walls. The hanging garden ecosystem is fragile, it contains a number of T&E species and the biologic community is highly dependent on the geology, geohydrology and topography for its existence. I suspect soil development is a factor too.

So the project would entail developing a GIS layer as a first-step in completing the inventory of hanging gardens in the parks. I believe this would be an extension of Cathleen May's earlier work. Perhaps we could put together a team of graduate students, a geologist-hydrologist, a biologist-ecologist and a GIS specialist, maybe through the Geoscientists-in-the-Parks program, I&M funds, both, or even other sources. Using geologic and topographic maps, plus information on existing hanging garden locations, they could develop a model to find new locations. This would be the inventory portion of the project.

The second step would be to establish good baseline information. This might include:

Geology - detailed descriptions of the formations and contacts where the gardens are found. What constitutes a seep (sandstone on shale, sandstone on limestone), what are the fracture controls, determination of the recharge area, nutrient potential from the formations, etc.

Hydrology - chemistry of the water (especially the nutrients), flow rates at the seep, residence time, transit routes from recharge to seep.

Biology - composition of the garden (vegetation, wildlife), T&E species, etc.

Soils - composition, quality, etc.

After the baseline is established, monitoring protocols can be developed and the monitoring can begin. I assume the monitoring will be mostly biologic and hydrologic to see what is changing. Changes in water chemistry, nutrients, flow rates will all probably affect the changes in the biologic community.

Another variable in the mix might be micro-climate changes. However, I suspect the residence time for the ground water may be long, and this would tend to lessen the affect of changes in micro-climates, especially the rainfall. However the change in distribution of precipitation, e.g. summer thunderstorms vs winter storms could make a difference.

There is probably a lot more to say about GIS applications, but I am not well enough versed in the subject to add much.

My initial thoughts were narrow -- to use this integrated science project as an opportunity to highlight the use of geology and geologic maps, but I realize that this project would likely have many other applications useful to the parks and integral to I&M.